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Nutrient Control in Sewage Lagoons

Volume II

Research Report No. 23

search Program for the Abatement of Municipal Pollution
under Provisions of the Canada-Ontario Agreement
on Great Lakes Water Quality

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These RESEARCH REPORTS describe the results of investigations funded under the Research Program for the Abatement of Municipal Pollution within the Provisions of the Canada-Ontario Agreement on Great Lakes Water Quality. They provide a central source of information on the studies carried out in this program through in-house projects by both Environment Canada and the Ontario Ministry of the Environment, and contracts with municipalities, research institutions and industrial organizations.

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POLLUTION CONTROL BRANCH

NUTRIENT CONTROL IN SEWAGE LAGOONS
VOLUME II

by

Pollutech Pollution Advisory Services, Ltd.
Oakville, Ontario

RESEARCH PROGRAM FOR THE ABATEMENT
OF MUNICIPAL POLLUTION WITHIN THE
PROVISIONS OF THE CANADA-ONTARIO
AGREEMENT ON GREAT LAKES WATER QUALITY

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ABSTRACT

This report describes an investigation of the effects of chemical addition on the operation of sewage lagoons, and the physical and/or chemical conditions in the lagoon on the removal of phosphorus.

Laboratory lagoon simulators were used to evaluate the effects of temperature, chemical dosage and influent phosphorus concentration on the performance of a typical lagoon. Raw sewage from the Village of Shelburne, Ontario was used as feed for the simulators.

It was found that the addition of 200 mg/l of alum effectively reduced phosphorus concentrations in the lagoon effluent to below 1 mg/l. Higher temperatures resulted in increased phosphorus in the effluent from untreated sewage. However, the addition of alum at 200 mg/l minimized this effect. The achievement of steady state operation in a lagoon with an 80 day retention time was found to require several months operation.

Alum dosage was found to be the most important factor in the phosphorus removal process in the lagoon. All other factors investigated in this study had a relatively minor effect on the phosphorus concentration in the chemically treated effluent.

RESUME

Le présent rapport traite de recherches concernant les effects sur le lagunage de l'eau usée suite à l'addition de produits chimiques, ainsi que les conditions physiques et chimiques causées par l'élimination du phosphore.

On a utilisé des dispositifs simulant le lagunage, pour évaluer en laboratoire l'action de la température, des quantités de produits utilisés et de la teneur en phosphore dans l'influent, sur le rendement d'une lagune type. Les dispositifs en question étaient alimentés en eau d'égout non traitée provenant du village de Shelburne, Ontario.

On a observé que l'addition de 200 mg/l d'alun permettait de réduire la teneur en phosphore de l'effluent à moins de 1 mg/l; l'élévation de la température favorisait la hausse de cette dernière dans l'effluent non traité. Toutefois, l'addition d'alun, à raison de 200 mg/l, a permis de parer à cet effet. L'obtention de conditions stables, dans une lagune à durée de rétention de 80 jours, nécessite quelques mois de fonctionnement préalable.

C'est l'alun qui s'est révélé le plus important pour l'élimination du phosphore; tous les autres facteurs étudiés n'avaient qu'une influence minime sur la teneur en phosphore de l'effluent ainsi traité.

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1. INTRODUCTION

Because of the documented role of phosphorus in eutrophication, substantial efforts are being made to limit its discharge in wastewater treatment plant effluents in Ontario. Some eighty sewage lagoons under the auspices of the Ontario Ministry of the Environment will require implementation of some type of phosphorus removal programme. Typically, the most common schemes for accomplishing the required degree of treatment involve the addition of alum or ferric chloride to the lagoon influent to precipitate phosphorus from the waste stream.

Pollutech Pollution Advisory Services Limited was retained through the Canada-Ontario Agreement on Great Lakes Water Quality to investigate the effects of chemical addition on the operation of sewage lagoons, and the physical and/or chemical conditions in the lagoon on the removal of phosphorus. The results of the initial phase of the study carried out in 1972-1973 were summarized in Canada-Ontario Agreement Research Report No. 8, "Nutrient Control in Sewage Lagoons". On the basis of these results, it was recommended, at that time, that the programme be continued to further explore the topic in greater detail. This report summarizes the results obtained during the 1973 programme. In addition, it briefly reviews the previous findings in order to give a complete understanding of the entire study.

2. SUMMARY OF PREVIOUS WORK

The work conducted in 1972 and early 1973 has been presented in detail in Canada-Ontario Agreement Research Report No. 8 and can be briefly summarized as follows:

(i) Both phosphorus and carbon were found to resolubilize from the anaerobic sludge deposits and the dissolution of phosphorus was found to be more extensive at higher temperatures.

(ii) Little variation in pH was found throughout the study.

(iii) Alum dosages of 200 mg/l controlled the discharge of phosphorus in the lagoon effluents and limited the resolubilization of phosphorus from the sludge.

(iv) The effect of low dissolved oxygen concentrations on phosphorus leaching was studied and preliminary data indicated that phosphorus was released from bottom deposits under low oxygen concentration. The addition of alum controlled this leaching. However, it was felt that data collected during the initial phase of the work were not sufficient to make any definite conclusion.

(v) The computer model developed to simulate the reactions occurring in the chemically-treated lagoon did not provide reasonable results because of the complex nature of the reactions taking place in the system. These reactions include physical and biological phenomena which cannot be adequately described by mathematical equilibrium schemes. The programme listing is presented in Appendix I of this report.

In the remainder of this report, information from the previous investigation will be incorporated whenever it is felt that these results are meaningful to the overall interpretation of the study.

3. OBJECTIVES

Based on the results obtained in the initial phase of the study, the original objectives were modified in order to establish the following:

(i) The relative effect of variations in temperature, alum dosage, and influent phosphorus concentration on the overall performance of the lagoon;

(ii) The long-term effect of alum treatment on phosphorus resolubilization from the sludge layer;

(iii) The effect of mixing the sludge deposits with the lagoon liquid contents on the dissolution of precipitated phosphorus; and,

(iv) The effect of a significant change in the alum dosage on the operation of the lagoon and the time required for a lagoon of 80 days retention time to adjust to this change.

4. PROCEDURE

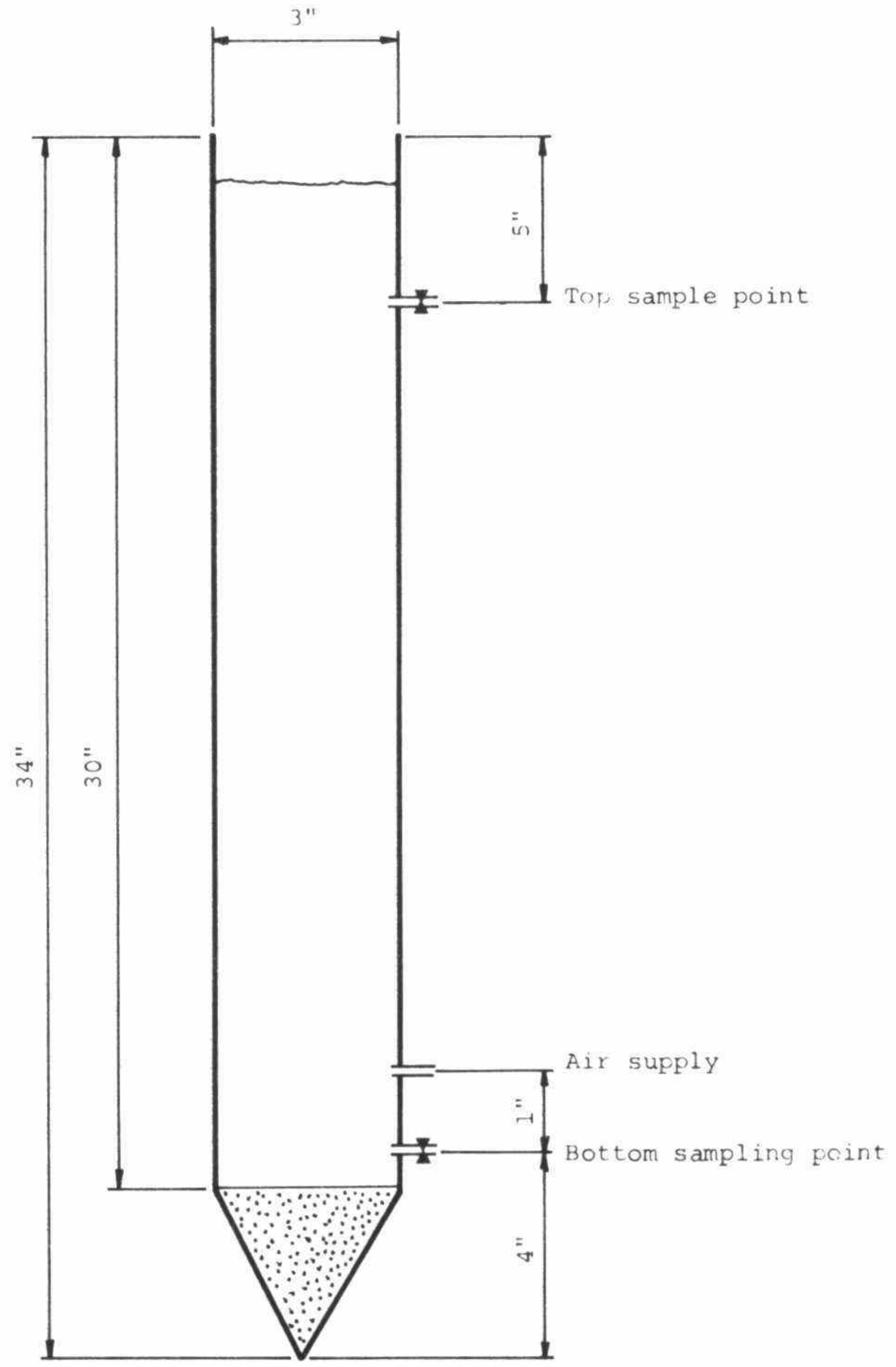
Laboratory lagoon simulators, as illustrated schematically in Figure 1, were operated in such a way as to evaluate the effects of temperature, chemical dosage and influent phosphorus concentration on the performance of a typical sewage lagoon. Seasonal temperature cycles were simulated by alternating the laboratory lagoons between ambient conditions (approximately 23°C) and 5°C. In the initial stages of the study, oxygen was provided to the units through a sparger system at minimal air flow rates. However, an attempt was also made to utilize only the photosynthetic activity of the algal growth as a source of oxygen for the biological degradation of the waste.

The laboratory lagoon simulators were operated at a nominal residence time of 80-days and fed Shelburne sewage five-times per week. The effect of chemical addition was evaluated by comparison of the operation of lagoons handling sewage treated with 200 mg/l alum with control lagoons fed untreated sewage. The units referred to as 1A and 1B were those dosed with alum at 200 mg/l from the beginning of the study; lagoons 2A and 2B were control units. The first cycle of the A-simulators was at ambient temperatures, while the B-units were initially operated at 5°C.

To evaluate the response of the system to changes in chemical dosage, the alum addition to unit 1A was decreased to 100 mg/l after forty-one weeks of operation. At the same time, chemical treatment of the feed to control 2A was commenced at 200 mg/l to determine the start-up period required for the system .

The lagoon simulators were sampled weekly from the top and bottom sampling ports and analyzed for total phosphorus, BOD and pH. Orthophosphate and total soluble phosphorus were also monitored periodically. Determination of the dissolved oxygen concentration was carried out at the

FIGURE 1 SCHEMATIC DIAGRAM OF LABORATORY SIMULATOR



top and bottom of the units during the initial period; however, very little difference in these results was found and therefore the dissolved oxygen was measured only in the middle of the units later in the study.

5. RESULTS

The quality of the raw sewage feed to the laboratory lagoon simulators is given in Table 1. The phosphorus concentration, as illustrated graphically in Figures 2 and 3, was found to vary significantly, averaging 8.9 mg/l with a range of 3.9 to 13.2 mg/l during the entire study. The average BOD of the raw sewage was 120 mg/l and the degree of variation was similar to the phosphorus results with a range of 37 to 197 mg/l. There was little variation in the pH of raw sewage.

The dissolved oxygen concentration and pH in the treated and control units are summarized in Tables 2 and 3, respectively. During the period of artificial aeration, the dissolved oxygen levels were maintained close to saturation. It was felt, however, that even at the minimal air flowrates used, sufficient mixing was provided in the simulators to prevent stratification within the system. Such stratification often occurs in full-scale lagoons. Therefore, the lagoons were operated without an external air supply during the fifteenth and sixteenth weeks and from the thirty-fourth week until the end of the study.

The dissolved oxygen content of the lagoons was found to be highly variable during these periods, an observation not readily attributable to any single cause. It is recognized that the oxygen level maintained by surface contact and algal photosynthesis is a very sensitive parameter, dependent on such uncontrollable variables as air currents and lighting conditions in the laboratory, agitation during movement of the simulators, temperature of the liquid and degree of mixing during sampling and feeding of the units.

While it was intended to evaluate the effect of dissolved oxygen tension on the resolubilization of phosphorus from the sludges, no conclusive results could be obtained due to these random variations in the oxygen concentration

TABLE 1. RAW SEWAGE QUALITY
(Village of Shelburne)

SAMPLING DATE	pH	BOD_5 (mg/l)	TOTAL PHOSPHORUS (mg/l)
19/9/72	7.5	37	8.8
11/10/72	7.1	126	12.3
26/10/72	7.6	107	8.8
23/11/72	-	182	9.7
9/1/73	-	-	11.4
6/2/73	8.5	106	9.0
5/3/73	7.5	119	10.5
11/4/73	7.6	94	4.8
15/5/73	7.5	107	3.9
21/6/73	7.5	-	6.0
13/8/73	7.5	127	8.9
2/10/73	-	197	13.2
Average	7.6	120	8.9

TABLE 2. pH AND DISSOLVED OXYGEN CONCENTRATIONS IN CHEMICALLY TREATED LAGOON SIMULATORS

		UNIT 1A (23°C)				UNIT 1B (5°C)			
		pH		Dissolved Oxygen (mg/l)		pH		Dissolved Oxygen (mg/l)	
Sampling Date	Duration of Study (No. of Weeks)	Top of Unit	Bottom of Unit	Top of Unit	Bottom of Unit	Top of Unit	Bottom of Unit	Top of Unit	Bottom of Unit
28/9/72		-	-	-	-	-	-	-	-
6/10/72		-	-	-	-	-	-	-	-
13/10/72	1	-	-	-	-	-	-	-	-
20/10/72	2	7.7	7.6	-	-	8.1	8.0	-	-
26/10/72	3	-	-	7.9	7.7	-	-	10.8	10.8
2/11/72	4	7.6	7.8	7.6	7.5	8.1	7.5	10.7	10.7
9/11/72	5	7.6	7.6	6.9	6.4	8.0	8.0	10.8	10.4
16/11/72	6	7.7	7.7	7.2	6.9	8.0	7.4	10.8	10.4
23/11/72	7	7.8	7.6	7.2	6.7	8.2	7.4	10.8	9.8
30/11/72	8	8.0	7.8	6.5	5.1	8.2	7.5	10.4	9.0
		UNIT INTERCHANGED FROM LABORATORY TO REFRIGERATOR (5°C)				UNIT INTERCHANGED FROM REFRIGERATOR TO LABORATORY (23°C)			
7/12/72	9	8.0	7.8	11.4	11.1	8.0	7.8	4.3	3.8
14/12/72	10	8.0	7.7	10.5	10.3	8.0	7.9	5.2	4.9
21/12/72	11	8.3	8.1	9.3	9.3	8.2	8.2	6.1	6.0
29/12/72	12	8.1	-	9.1	-	7.9	-	6.0	-
5/1/73	13	8.0	7.6	8.8	8.8	7.7	7.6	7.4	7.3
12/1/73	14	8.0	7.7	8.9	8.8	7.9	7.8	7.1	7.0
19/1/73	15*	-	-	3.5	-	-	-	.6	-
26/1/73	16*	-	-	.65	-	-	-	.6	-
1/2/73	17	-	-	8.2	8.2	-	-	5.9	5.8
9/2/73	18	8.2	7.9	-	-	7.9	7.8	5.6	5.4

* Operation without external air supply.

TABLE 2. (Cont'd)

Sampling Date	Duration of Study (No. of Weeks)	UNIT 1A (23°C)			UNIT 1B (5°C)		
		pH		Dissolved Oxygen (mg/l)	pH		Dissolved Oxygen (mg/l)
		Top of Unit	Bottom of Unit	Middle of Unit	Top of Unit	Bottom of Unit	Middle of Unit
24/2/73	20	-	-	-	-	-	-
2/3/73	21	7.6	7.6	-	7.9	7.8	-
		UNIT INTERCHANGED FROM REFRIGERATOR TO LABORATORY (23°C)			UNIT INTERCHANGED FROM LABORATORY TO REFRIGERATOR (5°C)		
9/3/73	22	8.2	7.95	-	7.9	8.1	-
16/3/73	23	8.0	-	-	7.8	-	-
23/3/73	24	7.7	-	7.4	7.9	-	11.9
30/3/73	25	8.1	-	7.6	8.2	-	11.3
6/4/73	26	8.1	-	7.1	8.2	-	11.2
13/4/73	27	8.2	-	-	8.2	-	-
		UNIT INTERCHANGED FROM LABORATORY TO REFRIGERATOR			UNIT INTERCHANGED FROM REFRIGERATOR TO LABORATORY		
20/4/73	28	8.2	-	-	8.25	-	-
27/4/73	29	8.25	-	12.5	8.10	-	8.0
4/5/73	30	8.2	-	-	8.25	-	-
11/5/73	31	8.2	-	12.5	8.3	-	8.2
18/5/73	32	8.25	-	12.8	8.3	-	8.3
25/5/73	33	-	-	-	-	-	-
28/5/73	34	8.3	-	12.1	8.3	-	8.0
		UNIT INTERCHANGED FROM REFRIGERATOR TO LABORATORY			UNIT INTERCHANGED FROM LABORATORY TO REFRIGERATOR		

TABLE 2. (Cont'd)

Sampling Date	Duration of Study (No. of Weeks)	UNIT 1A (23°C)			UNIT 1B (5°C)		
		pH		Dissolved Oxygen (mg/l)	pH		Dissolved Oxygen (mg/l)
		Top of Unit	Bottom of Unit	Middle of Unit	Top of Unit	Bottom of Unit	Middle of Unit
29/5/73	34	AERATION STOPPED					
30/5/73	34	7.75	7.75	-	8.15	8.15	-
1/6/73	34	7.7	7.7	-	8.1	8.1	-
5/6/73	35*	7.7	7.7	-	7.9	7.8	-
8/6/73	35	7.5	7.5	1.1	7.55	7.55	6.8
12/6/73	36	7.6	7.7	.8	7.8	7.75	6.6
15/6/73	36	7.6	7.6	.9	7.65	7.7	6.6
19/6/73	37	7.95	8.0	-	7.9	7.8	-
22/6/73	37	7.75	7.75	5.7	7.55	7.5	7.9
26/6/73	38	7.7	7.7	3.4	7.5	7.45	7.6
3/7/73	39	7.55	7.55	2.7	7.6	7.55	8.4
6/7/73	39	7.7	7.6	2.75	7.5	7.45	7.75
10/7/73	40	7.65	7.6	-	7.6	7.43	-
13/7/73	40	7.6	7.55	1.7	7.65	7.4	10.0
18/7/73	41	7.55	7.6	-	7.65	7.3	-
		UNIT INTERCHANGED FROM LABORATORY TO REFRIGERATOR Alum Dosage Decreased to 100 mg/l			UNIT INTERCHANGED FROM REFRIGERATOR TO LABORATORY		

* Operation without external air supply from week 35 to end of study period.

TABLE 2. (Cont'd)

Sampling Date	Duration of Study (No. of Weeks)	UNIT 1A (23°C)			UNIT 1B (5°C)		
		pH		Dissolved Oxygen (mg/l)	pH		Dissolved Oxygen (mg/l)
		Top of Unit	Bottom of Unit	Middle of Unit	Top of Unit	Bottom of Unit	Middle of Unit
19/7/73	41	7.65	7.6	-	7.45	7.4	-
26/7/73	42	7.7	7.7	6.5	7.5	7.45	.7
2/8/73	43	6.8	6.85	-	7.6	7.55	-
8/8/73	44	6.75	6.8	-	7.5	7.5	-
16/8/73	45	7.0	7.0	.3	7.5	7.45	.9
23/8/73	46	7.8	7.8	-	8.15	8.15	-
30/8/73	47	7.6	7.65	.7	7.9	7.95	.5
		UNIT INTERCHANGED FROM REFRIGERATOR TO LABORATORY			UNIT INTERHCNAGED FROM LABORATORY TO REFRIGERATOR		
6/9/73	48	7.6	7.65	.3	7.7	7.68	4.0
13/9/73	49	7.9	7.9	.3	7.8	7.8	4.2
20/9/73	50	8.2	8.2	.4	7.9	7.9	4.25
28/9/73	51	8.0	8.0	-	7.7	7.63	-
5/10/73	52	8.1	8.1	.4	7.6	7.6	2.2
12/10/73	53	8.0	7.93	-	7.53	7.5	-
19/10/73	54	8.08	8.0	-	7.63	7.6	-

TABLE 3. pH AND DISSOLVED OXYGEN CONCENTRATIONS IN CONTROL LAGOON SIMULATORS

Sampling Date	Duration of Study (No. of Weeks	UNIT 2A (23°C)				UNIT 2B (5°C)			
		pH		Dissolved Oxygen (mg/l)		pH		Dissolved Oxygen (mg/l)	
		Top of Unit	Bottom of Unit	Top of Unit	Bottom of Unit	Top of Unit	Bottom of Unit	Top of Unit	Bottom of Unit
28/9/72		-	-	-	-	-	-	-	-
6/10/72		-	-	-	-	-	-	-	-
13/10/72	1	-	-	-	-	-	-	-	-
20/10/72	2	8.2	8.1	-	-	8.05	8.15	-	-
26/10/72	3	-	-	7.8	7.8	-	-	10.9	10.9
2/11/72	4	8.1	8.1	7.5	7.4	8.2	8.2	11.5	11.5
9/11/72	5	7.9	7.9	6.8	6.4	8.2	8.2	11.5	11.4
16/11/72	6	8.0	8.0	7.3	7.0	8.2	8.2	11.4	11.1
23/11/72	7	7.95	7.8	5.5	4.8	8.15	8.2	11.2	11.0
30/11/72	8	8.1	8.0	5.7	4.3	8.3	8.0	11.0	9.5
		UNIT INTERCHANGED FROM LABORATORY TO REFRIGERATOR				UNIT INTERCHANGED FROM REFRIGERATOR TO LABORATORY			
7/12/72	9	8.0	7.9	10.8	10.4	8.3	8.2	4.1	3.4
14/12/72	10	8.3	8.2	10.8	10.5	8.2	8.0	4.8	4.5
21/12/72	11	8.3	8.3	8.7	8.6	8.35	8.3	5.7	5.5
29/12/72	12	8.2	-	8.8	-	8.2	-	5.6	-
5/1/73	13	8.0	7.8	9.1	9.0	7.55	7.7	6.9	6.7
12/1/73	14	8.2	8.3	8.9	8.9	8.2	8.0	7.2	7.2
19/1/73	15*	-	-	3.6	-	-	-	.65	-
26/1/73	16*	-	-	.65	-	-	-	.6	-
1/2/73	17	-	-	8.5	8.5	-	-	6.5	6.4
9/2/73	18	8.4	8.0	8.8	8.8	8.1	8.0	5.7	5.6
	19	-	-	-	-	-	-	-	-

TABLE 3. (Cont'd)

Sampling Date	Duration of Study (No. of Weeks)	UNIT 2A (23°C)			UNIT 2B (5°C)		
		pH		Dissolved Oxygen (mg/l)	pH		Dissolved Oxygen (mg/l)
		Top of Unit	Bottom of Unit	Middle of Unit	Top of Unit	Bottom of Unit	Middle of Unit
24/2/73	20	-	-	-	-	-	-
2/3/73	21	8.2	7.9	-	8.0	8.1	-
		UNIT INTERCHANGED FROM REFRIGERATOR TO LABORATORY			UNIT INTERCHANGED FROM LABORATORY TO REFRIGERATOR		
9/3/73	22	8.0	7.95	-	8.4	8.35	-
16/3/73	23	7.9	-	-	8.2	-	-
23/3/73	24	7.5	-	7.5	7.9	-	11.8
30/3/73	25	8.3	-	7.6	8.4	-	11.5
6/4/73	26	8.25	-	7.3	8.2	-	11.4
13/4/73	27	8.3	-	-	8.3	-	-
		UNIT INTERCHANGED FROM LABORATORY TO REFRIGERATOR			UNIT INTERCHANGED FROM REFRIGERATOR TO LABORATORY		
20/4/73	28	8.35	-	-	8.4	-	-
27/4/73	29	8.35	-	12.0	8.35	-	7.8
4/5/73	30	8.4	-	-	8.4	-	-
11/5/73	31	8.5	-	11.8	8.45	-	8.0
18/5/73	32	8.55	-	12.2	8.5	-	8.4
25/5/73	33	-	-	-	-	-	-
28/5/73	34	8.2	-	12.3	8.4	-	8.2
		UNIT INTERCHANGED FROM REFRIGERATOR TO LABORATORY			UNIT INTERCHANGED FROM LABORATORY TO REFRIGERATOR		

TABLE 3. (Cont'd)

Sampling Date	Duration of Study (No. of Weeks)	UNIT 2A (23^{o}C)			UNIT 2B (5^{o}C)		
		pH		Dissolved Oxygen (mg/l)	pH		Dissolved Oxygen (mg/l)
		Top of Unit	Bottom of Unit	Middle of Unit	Top of Unit	Bottom of Unit	Middle of Unit
29/5/73	34	-	-	8.1	-	-	12.0
30/5/73	34	7.85	7.85	-	8.25	8.25	-
1/6/73	34	7.83	7.83	-	8.23	8.15	-
5/6/73	35 *	7.9	7.9	-	8.0	8.0	-
8/6/73	35	7.7	7.65	.1	7.65	7.65	3.9
12/6/73	36	7.95	8.0	.1	7.95	7.95	2.1
15/6/73	36	7.85	7.85	.2	7.8	7.8	1.9
19/6/73	37	8.05	8.10	-	8.1	7.9	-
22/6/73	37	7.85	7.9	.1	7.65	7.65	1.8
26/6/73	38	7.75	7.8	.2	7.6	7.6	2.0
3/7/73	39	7.8	7.75	.3	7.55	7.5	1.0
6/7/73	39	7.85	7.85	.4	7.55	7.55	.9
10/7/73	40	7.9	7.85	-	7.6	7.5	-
13/7/73	40	7.9	7.9	.3	7.5	7.45	1.25
18/7/73	41	7.85	7.9	-	7.55	7.5	-
		UNIT INTERCHANGED FROM LABORATORY TO REFRIGERATOR Commencement of 200 mg/l alum dosage			UNIT INTERCHANGED FROM REFRIGERATOR TO LABORATORY		

* Operation without external air supply from week week 35 to end of study period.

TABLE 3. (Cont'd)

Sampling Date	Duration of Study (No. of Weeks)	UNIT 2A (23°C) pH Top of Unit	UNIT 2A (23°C) pH Bottom of Unit	UNIT 2A (23°C) Dissolved Oxygen (mg/l) Middle of Unit	UNIT 2B (5°C) pH Top of Unit	UNIT 2B (5°C) pH Bottom of Unit	UNIT 2B (5°C) Dissolved Oxygen (mg/l) Middle of Unit
19/7/73	41	7.8	7.75	-	7.5	7.5	-
26/7/73	42	7.73	7.7	.8	7.75	7.75	.2
2/8/73	43	7.65	7.6	-	7.95	7.95	-
8/8/73	44	7.65	7.6	-	7.8	7.7	-
16/8/73	45	7.45	7.5	2.6	7.8	7.8	.2
23/8/73	46	8.05	8.0	-	8.2	8.15	-
30/8/73	47	7.9	8.0	1.1	8.2	8.2	.6
		UNIT INTERCHANGED FROM REFRIGERATOR TO LABORATORY			UNIT INTERCHANGED FROM LABORATORY TO REFRIGERATOR		
6/9/73	48	7.8	7.8	.25	8.0	7.93	2.1
13/9/73	49	8.0	7.97	.25	7.9	7.88	1.0
20/9/73	50	8.2	8.2	.45	8.05	8.05	1.3
28/9/73	51	8.0	8.0	-	7.85	7.83	-
5/10/73	52	7.95	7.9	.4	7.8	7.8	.6
12/10/73	53	7.9	7.88	-	7.72	7.7	-
19/10/73	54	8.0	7.9	-	7.8	7.8	-

within the lagoons. Low dissolved oxygen levels did appear to affect the rate of dissolution of phosphorus from the control lagoon in the initial phase of the study (Canada-Ontario Agreement Research Report No. 8), but this trend could not be confirmed during the more intensive investigation.

The BOD removal efficiency of the lagoon simulators is summarized in Tables 4 and 5. Effluent BOD concentrations in the laboratory units were found to be lower than those in the full-scale lagoon at Shelburne, as shown in Table 6. The higher effluent BOD's observed in the full-scale system may reflect a relatively higher ratio of sludge deposits to liquid volume. In this sense, the laboratory lagoons may not have matured sufficiently to provide accurate simulation of the recirculation of organics from the sludge to the overlying layers.

Figure 2 illustrates the effluent phosphorus levels from the chemically-treated units. The results indicate that an alum dosage of 200 mg/l controls the discharge of phosphorus. However, a period of some thirty-five weeks was required to stabilize the system and obtain an effluent containing less than 0.5 mg/l phosphorus. An alum dosage of 100 mg/l was found to be insufficient, as indicated by effluent phosphorus concentrations in excess of 1 mg/l and equilibrium still was not achieved in this simulator at the conclusion of the study (13 weeks after the dosage change), because of the long retention time of the system.

The performance of the control units was quite erratic, as evidenced by the effluent phosphorus concentrations illustrated in Figure 3. Some decrease in phosphorus through the units was evident during the periods of high influent phosphorus concentrations but the phosphorus concentration in the effluent was above the level in the raw sewage for several weeks when the phosphorus in the influent was relatively low. These simulators appeared to function as equalization basins rather than as a phosphorus removal system.

TABLE 4. BOD$_5$ IN THE EFFLUENTS FROM CHEMICALLY TREATED LAGOON SIMULATORS

Sampling Date	Duration of Study (No. of Weeks	UNIT 1A (23°C) Effluent BOD$_5$ (mg/l)	UNIT 1B (5°C) Effluent BOD$_5$ (mg/l)
28/9/72		13.5	27.5
6/10/72		14.0	34.0
13/10/72	1	18.0	18.0
20/10/72	2	4.0	11.0
26/10/72	3	9.0	6.0
2/11/72	4	3.0	6.0
9/11/72	5	3.0	4.0
16/11/72	6	2.0	2.0
23/11/72	7	5.0	4.0
30/11/72	8	3.0	3.0
UNIT INTERCHANGED FROM		LABORATORY TO REFRIGERATOR (5°C)	REFRIGERATOR TO LABORATORY (23°C)
7/12/72	9	2.0	6.0
14/12/72	10	3.0	3.0
21/12/72	11	3.0	12.0
29/12/72	12	-	-
5/1/73	13	1.0	3.0
12/1/73	14	1.0	5.0
19/1/73	15 *	-	-
26/1/73	16 *	2.0	3.5
1/2/73	17	-	-
9/2/73	18	4.0	4.0
	19	-	-
24/2/73	20	3.5	4.0
2/3/73	21	-	-
UNIT INTERCHANGED FROM		REFRIGERATOR TO LABORATORY	LABORATORY TO REFRIGERATOR
9/3/73	22	-	-
16/3/73	23	-	-
23/3/73	24	2.0	5.0
30/3/73	25	-	-
6/4/73	26	-	-
13/4/73	27	5.0	2.0
UNIT INTERCHANGED FROM		LABORATORY TO REFRIGERATOR	REFRIGERATOR TO LABORATORY

* No external air supply.

TABLE 4. (Cont'd)

Sampling Date	Duration of Study (No. of Weeks)	UNIT 1A (23°C) Effluent BOD_5 (mg/l)	UNIT 1B (5°C) Effluent BOD_5 (mg/l)
20/4/73	28	-	-
27/4/73	29	-	-
4/5/73	30	-	-
11/5/73	31	-	-
18/5/73	32	-	-
25/5/73	33	-	-
28/5/73	34	-	-
UNIT INTERCHANGED FROM		REFRIGERATOR TO LABORATORY	LABORATORY TO REFRIGERATOR
30/5/73	34	-	-
1/6/73	34	16.0	10.0
5/6/73	35*	6.0	2.0
8/6/73	35	-	-
12/6/73	36	-	-
15/6/73	36	11.0	6.0
19/6/73	37	-	-
22/6/73	37	-	-
26/6/73	38	3.0	3.0
3/7/73	39	-	-
6/7/73	39	4.0	1.0
10/7/73	40	-	-
13/7/73	40	-	-
18/7/73	41	2.0	4.0
UNIT INTERCHANGED FROM		LABORATORY TO REFRIGERATOR	REFRIGERATOR TO LABORATORY
	Alum Dosage Decreased to 100 mg/l		
19/7/73	41	-	-
26/7/73	42	10.0	7.0
2/8/73	43	-	-
8/8/73	44	24.0	6.0
16/8/73	45	-	-
23/8/73	46	26.0	7.5
30/8/73	47	-	-
UNIT INTERCHANGED FROM		REFRIGERATOR TO LABORATORY	LABORATORY TO REFRIGERATOR

* No external air supply from week 35 to end of study.

TABLE 4. (Cont'd)

Sampling Date	Duration of Study (No. of Weeks)	UNIT 1A (23°C) Effluent BOD_5 (mg/l)	UNIT 1B (5°C) Effluent BOD_5 (mg/l)
6/9/73	48	-	-
13/9/73	49	-	-
20/9/73	50	12.0	2.0
28/9/73	51	-	-
5/10/73	52	10.0	5.0
12/10/73	53	-	-
19/10/73	54	10.0	10.0

TABLE 5. BOD_5 IN EFFLUENTS FROM CONTROL LAGOON SIMULATORS

Sampling Date	Duration of Study (No. of Weeks)	UNIT 2A (23°C) Effluent BOD_5 (mg/l)	UNIT 2B (5°C) Effluent BOD_5 (mg/l)
28/9/72		8.5	32.0
6/10/72		52.0	26.0
13/10/72	1	15.0	14.0
20/10/72	2	9.0	13.0
26/10/72	3	6.5	5.0
2/11/72	4	2.0	9.0
9/11/72	5	2.0	5.0
16/11/72	6	2.0	3.0
23/11/72	7	4.0	4.0
30/11/72	8	3.0	3.0
UNIT INTERCHANGED FROM		LABORATORY TO REFRIGERATOR (5°C)	REFRIGERATOR TO LABORATORY (23°C)
7/12/72	9	2.0	5.0
14/12/72	10	3.0	5.0
21/12/72	11	2.0	2.0
29/12/72	12	-	-
5/1/73	13	2.0	8.0
12/1/73	14	2.0	3.0
19/1/73	15	-	-
26/1/73	16	3.0	4.0
1/2/73	17	-	-
9/2/73	18	2.0	5.5
	19	-	-
24/2/73	20	2.0	5.5
2/3/73	21	-	-
UNIT INTERCHANGED FROM		REFRIGERATOR TO LABORATORY (23°C)	LABORATORY TO REFRIGERATOR (5°C)
9/3/73	22	-	-
16/3/73	23	-	-
23/3/73	24	7.0	1.0
30/3/73	25	-	-
6/4/73	26	-	-
13/4/73	27	4.0	1.0
UNIT INTERCHANGED FROM		LABORATORY TO REFRIGERATOR	REFRIGERATOR TO LABORATORY

TABLE 5. (Cont'd)

Sampling Date	Duration of Study (No. of Weeks)	UNIT 2A (23°C)	UNIT 2B (5°C)
		Effluent BOD_5 (mg/l)	Effluent BOD_5 (mg/l)
20/4/73	28	-	-
27/4/73	29	-	-
4/5/73	30	-	-
11/5/73	31	-	-
18/5/73	32	-	-
25/5/73	33	-	-
28/5/73	34	-	-
UNIT INTERCHANGED FROM		REFRIGERATOR TO LABORATORY	LABORATORY TO REFRIGERATOR
30/5/73	34	-	-
1/6/73	34	12.0	8.0
5/6/73	35	11.0	3.0
8/6/73	35	-	-
12/6/73	36	-	-
15/6/73	36	5.0	3.0
19/6/73	37	-	-
22/6/73	37	-	-
26/6/73	38	8.0	7.0
3/7/73	39	-	-
6/7/73	39	5.0	6.0
10/7/73	40	-	-
13/7/73	40	-	-
18/7/73	41	1.0	4.5
UNIT INTERCHANGED FROM		LABORATORY TO REFRIGERATOR	REFRIGERATOR TO LABORATORY
Commencement of 200 mg/l alum dosage			
19/7/73	41	-	-
26/7/73	42	8.0	8.0
2/8/73	43	-	-
8/8/73	44	2.0	6.0
16/8/73	45	-	-
23/8/73	46	7.0	9.5
30/8/73	47	-	-
UNIT INTERCHANGED FROM		REFRIGERATOR TO LABORATORY	LABORATORY TO REFRIGERATOR

TABLE 5. (Cont'd)

Sampling Date	Duration of Study (No. of Weeks)	UNIT 2A (23°C) Effluent BOD$_5$ (mg/l)	UNIT 2B (5°C) Effluent BOD$_5$ (mg/l)
6/9/73	48	-	-
13/9/73	49	-	-
20/9/73	50	3.7	2.5
28/9/73	51	-	-
5/10/73	52	12.0	7.0
12/10/73	53	-	-
19/10/73	54	10.0	10.0

FIGURE 2 PHOSPHORUS PROFILE OF FEED AND EFFLUENTS FROM CHEMICALLY TREATED LAGOON SIMULATORS

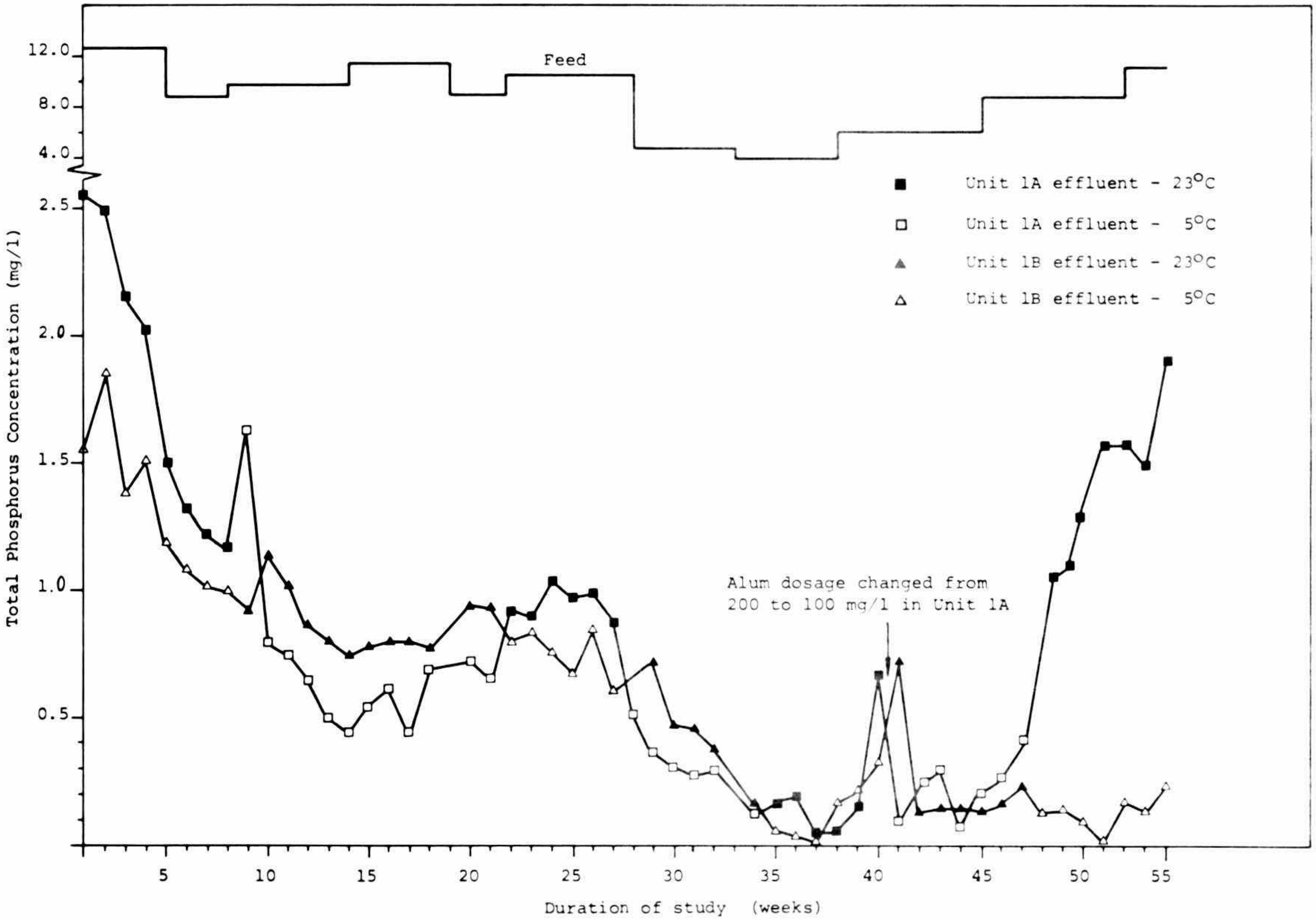


FIGURE 3 PHOSPHORUS PROFILE OF FEED AND EFFLUENTS FROM CONTROL LAGOON SIMULATORS

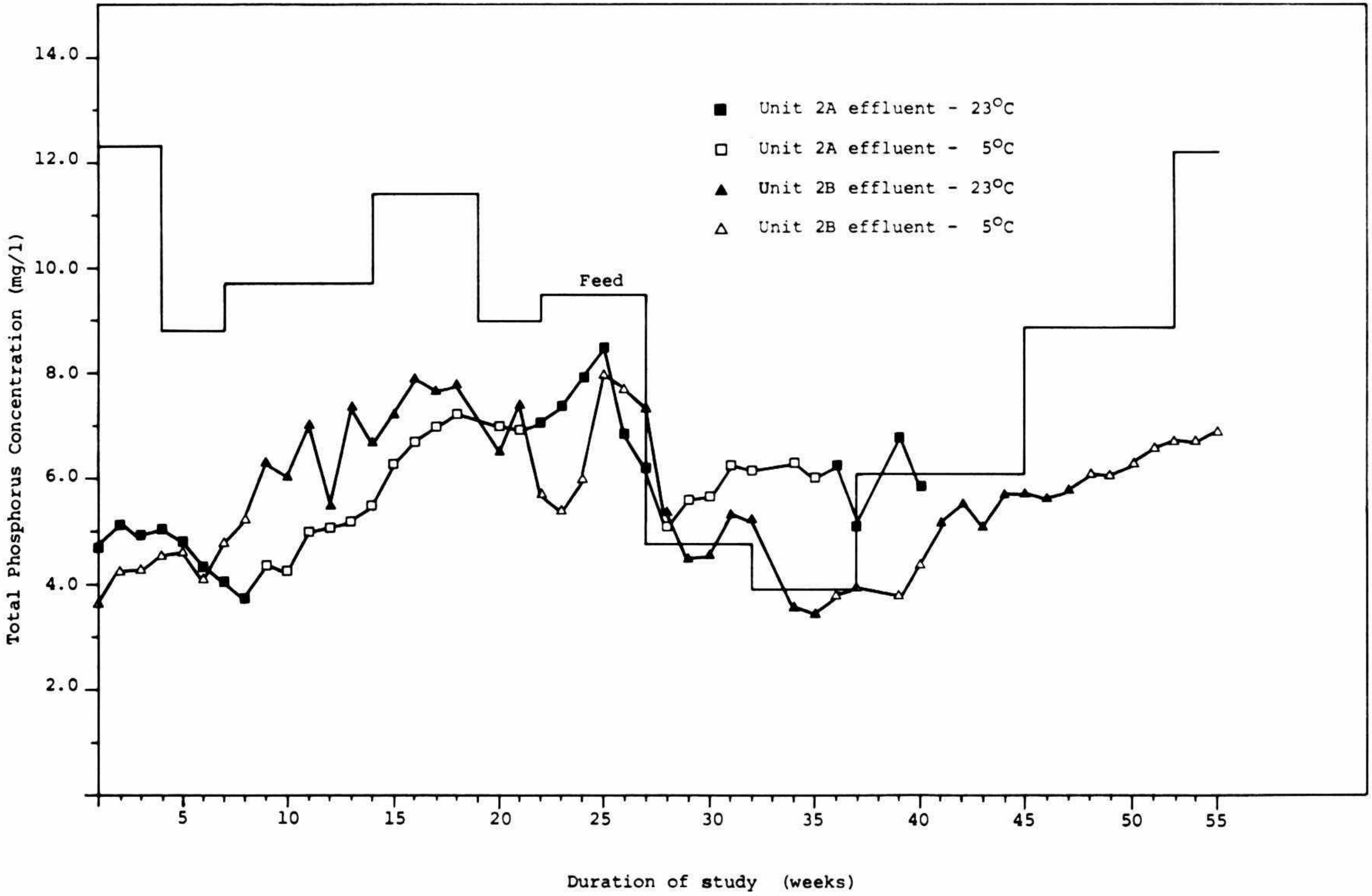


TABLE 6. EFFLUENTS FROM SEWAGE LAGOONS
(Village of Shelburne)

SAMPLING DATE	WEST LAGOON			EAST LAGOON		
	pH	BOD_5 (mg/l)	Total Phosphorus (mg/l)	pH	BOD_5 (mg/l)	Total Phosphorus (mg/l)
19/9/72	-	-	3.1	-	-	1.3
11/10/72	8.8	33	1.9	8.6	26	3.6
26/10/72	8.8	-	3.5	8.8	-	-
23/11/72	8.1	-	-	7.6	-	-
9/1/73	7.7	-	6.1	7.5	-	1.8
6/2/73	7.7	40	6.0	7.5	48	2.6
5/3/73	7.4	35	4.7	7.1	60	3.6
11/4/73	8.1	18	0.5	8.2	14	1.1
15/5/73	8.8	-	-	9.5	26	1.1
21/6/73	-	-	0.3	-	-	0.4
13/8/73	8.4	12	0.5	7.5	23	0.7
2/10/73	-	33	0.6	-	47	0.5
Average	8.2	29	2.7	8.0	35	1.7

Furthermore, a substantial algae bloom in Unit 2B resulted in a utilization of phosphorus by the algal mass and a subsequent decrease in the effluent phosphorus concentration.

The results of phosphorus determinations on the filtered and unfiltered lagoon samples are compared in Table 7. As no significant difference was found, the filtration step was deleted for the remainder of the normal lagoon operation.

The performance of the former control lagoon 2A from the commencement of chemical treatment at 200 mg/l alum is shown in Figure 4. Comparison of the results from the treated unit with the untreated control 2B indicates that the effect of chemical addition is evident after approximately two weeks. However, it is apparent that the period required to establish steady conditions in a lagoon with a retention time of 80 days is very long. Because of time limitations, this part of the study was terminated after 13 weeks of operation and before the system had attained equilibrium.

The ability of alum to control the discharge of phosphorus despite influent variations is shown in Figure 5. As the influent concentration increased during the last several weeks of the study, the effluent from the untreated lagoon (2B) followed the increasing trend whereas the phosphorus concentration from the lagoon treated with 200 mg/l alum (1B) was unaffected. Similarly, Figure 6 illustrates the response of the lagoon simulators to the commencement of 200 mg/l of alum dosage and to the reduction of dosage from 200 mg/l to 100 mg/l, respectively. The phosphorus concentration in the raw sewage was increasing during this period.

The effect of temperature and the influence of settled sludge deposits on the quality of the effluent is demonstrated in Figures 7 - 9. A probability plot was used for this data in order to alleviate the problem of differentiating between the effects of the control parameters and other random variations on the lagoon. It should be emphasized that these Figures are not intended to express

TABLE 7. EFFECT OF FILTRATION ON THE QUALITY OF LAGOON EFFLUENTS

SAMPLE IDENTIFICATION			TOTAL PHOSPHORUS (mg/l)	
UNIT	SAMPLING POINT	DATE	IN SUPERNATANT	IN FILTERED SUPERNATANT
1A	Top	Feb. 9/73	0.70	0.60
1A	Top	Mar. 2/73	0.65	0.55
1A	Top	May 28/73	0.13	0.15
1A	Bottom	Feb. 9/73	0.82	0.53
1A	Bottom	Mar. 2/73	0.75	0.60
1B	Top	Feb. 9/73	0.78	0.67
1B	Top	Mar. 2/73	0.95	0.78
1B	Top	May 28/73	0.15	0.15
1B	Bottom	Feb. 9/73	0.83	0.65
1B	Bottom	Mar. 2/73	0.95	0.85
2A	Top	Feb. 9/73	7.22	6.85
2A	Top	Mar. 2/73	6.94	6.97
2A	Top	May 28/73	5.70	5.57
2A	Bottom	Feb. 9/73	9.20	9.05
2A	Bottom	Mar. 2/73	7.95	7.95

TABLE 7. (Cont'd)

SAMPLE IDENTIFICATION			TOTAL PHOSPHORUS (mg/l)	
UNIT	SAMPLING POINT	DATE	IN SUPERNATANT	IN FILTERED SUPERNATANT
2B	Top	Feb. 9/73	7.80	7.25
2B	Top	Mar. 2/73	7.42	7.06
2B	Top	May 28/73	3.77	3.68
2B	Bottom	Feb. 9/73	8.00	7.65
2B	Bottom	Mar. 2/73	7.25	7.06

FIGURE 4 COMPARATIVE PHOSPHORUS PROFILES FOLLOWING START-UP OF CHEMICAL TREATMENT

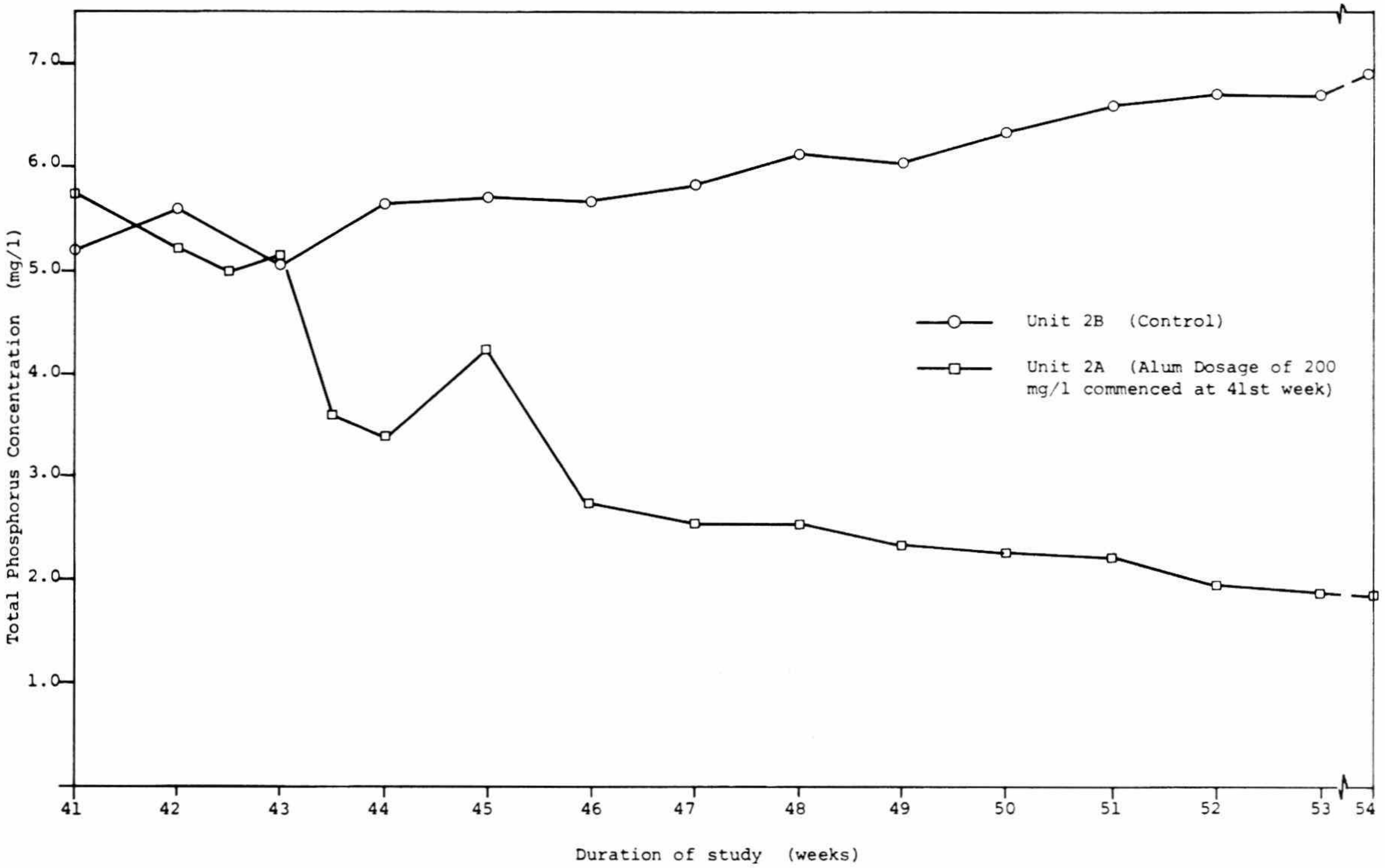


FIGURE 5 EFFECT OF PHOSPHORUS LOADING AND THE PHOSPHORUS PROFILE OF DOSED AND CONTROL LAGOON EFFLUENTS

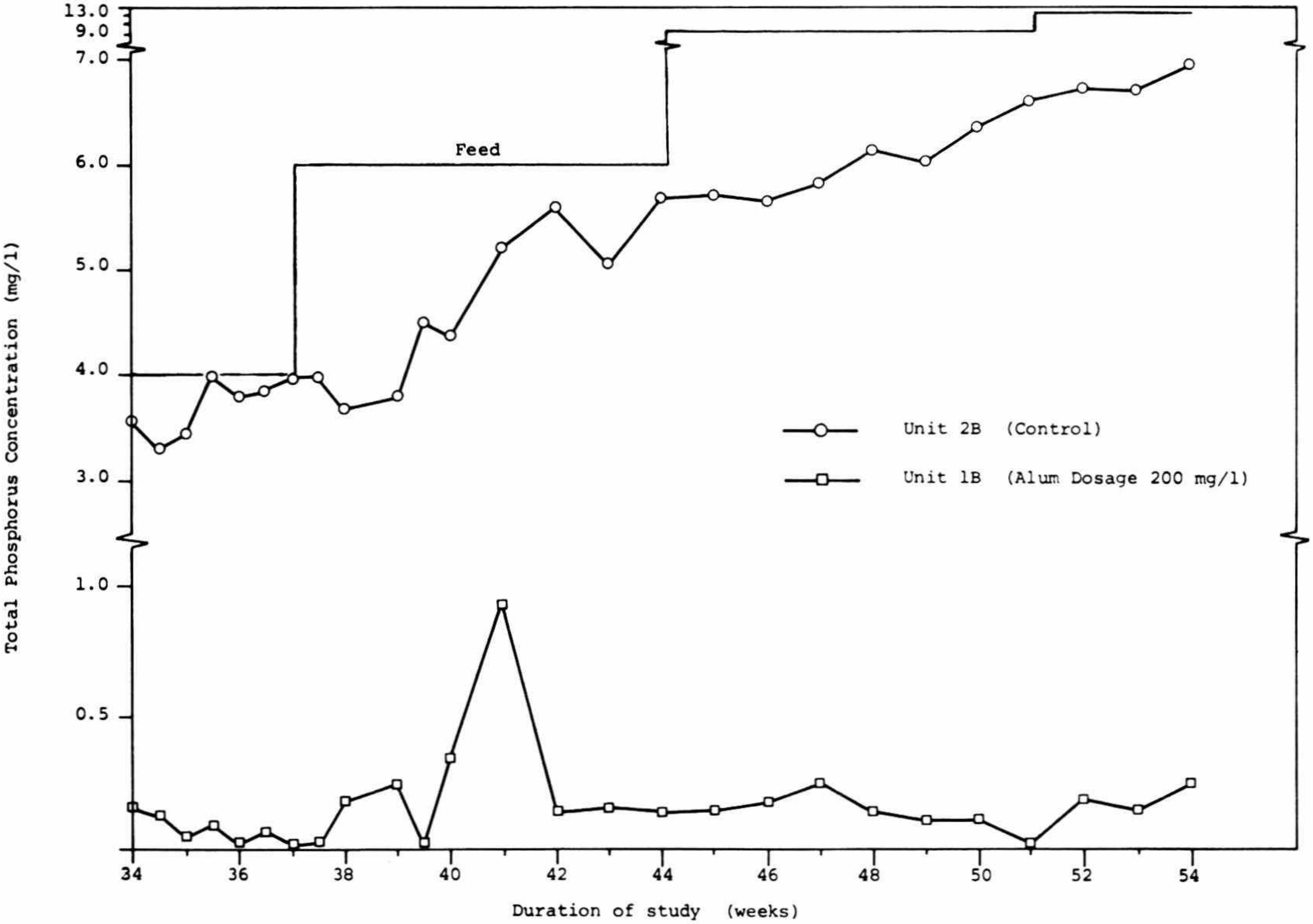


FIGURE 6 EFFECT OF THE CHANGE IN ALUM DOSAGE ON LAGOON PERFORMANCE

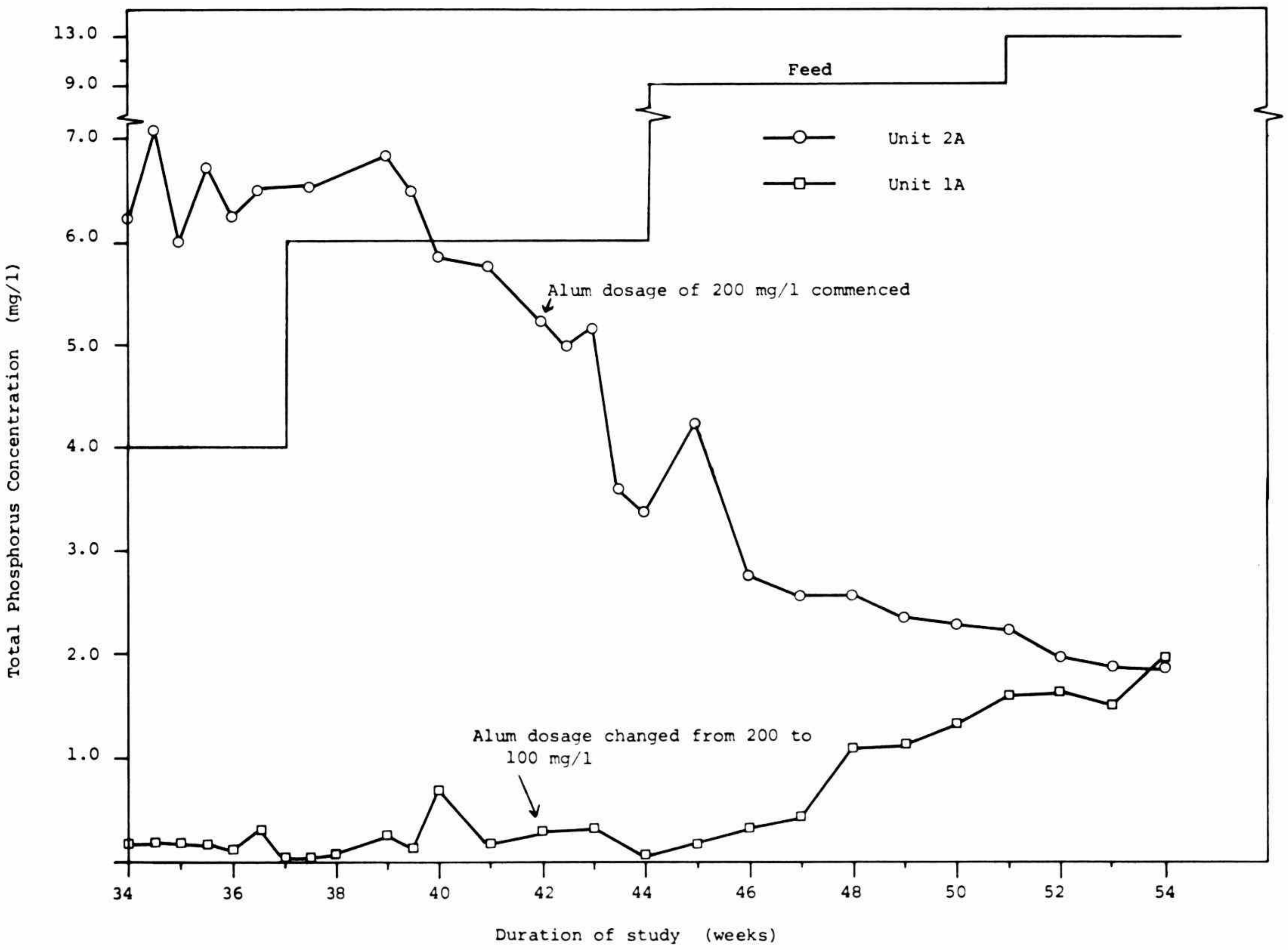


FIGURE 7 EFFECT OF TEMPEPATURE ON EFFLUENT PHOSPHORUS CONCENTRATIONS

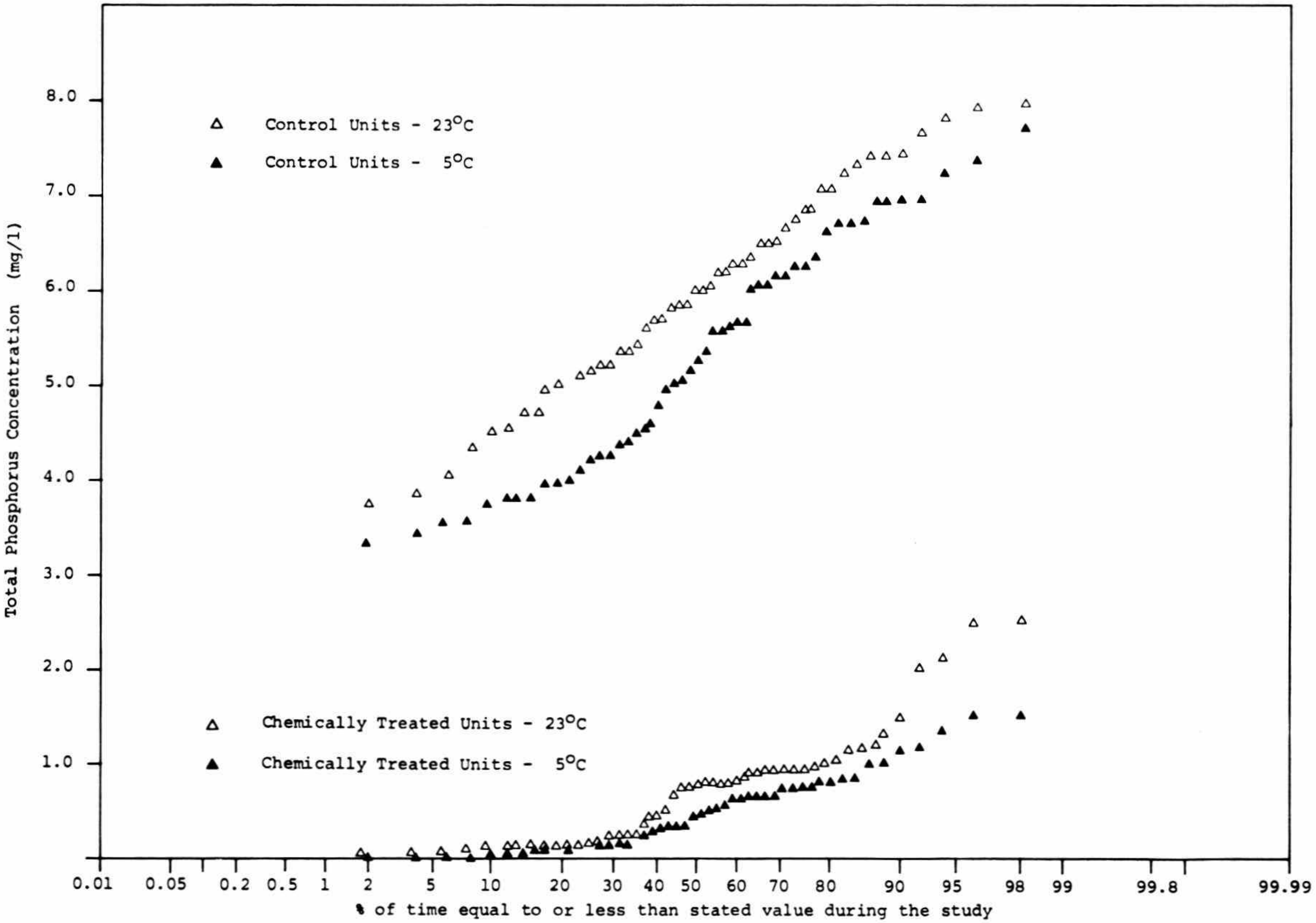


FIGURE 8 STRATIFICATION OF PHOSPHORUS IN LAGOONS AT 23°C

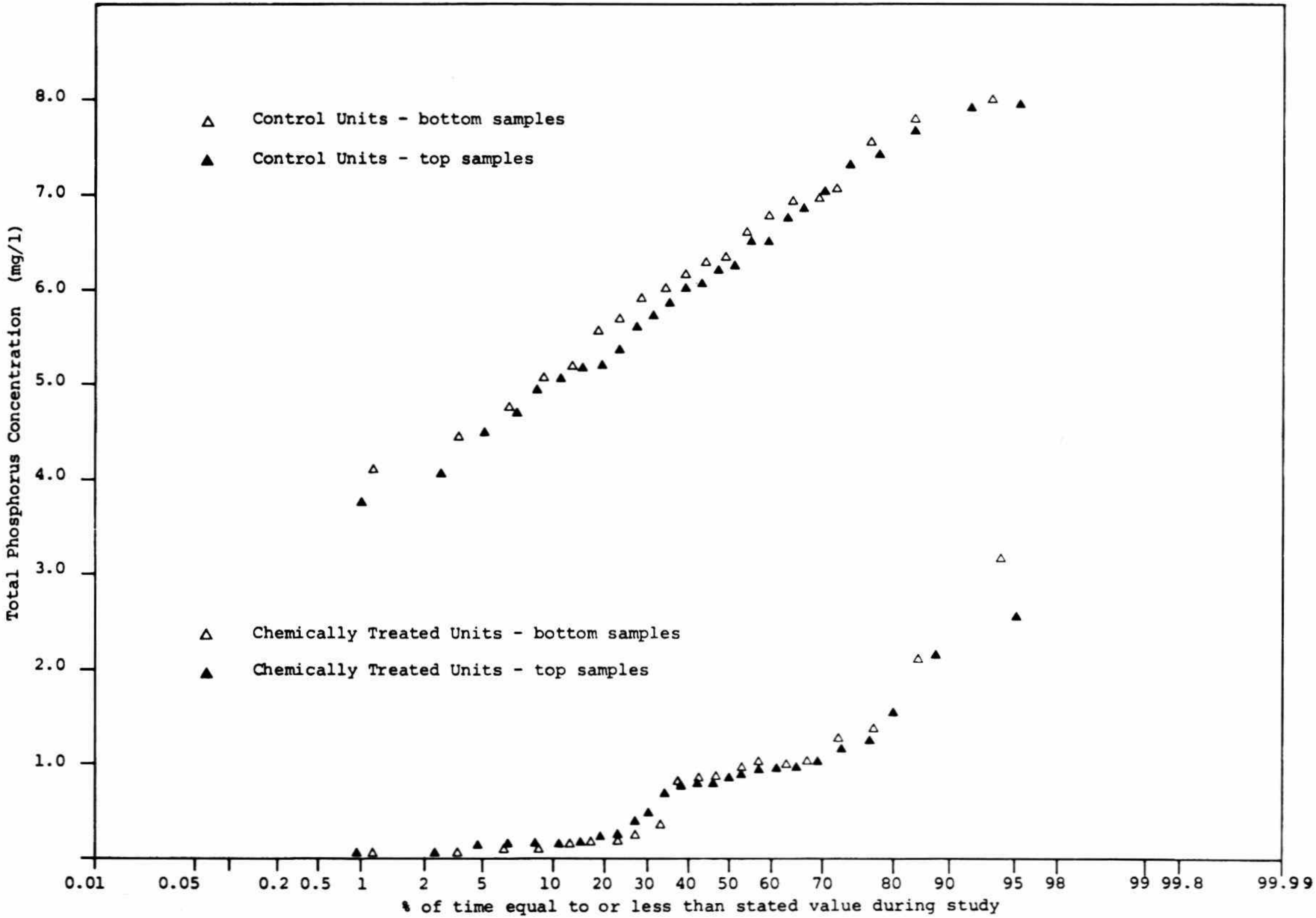
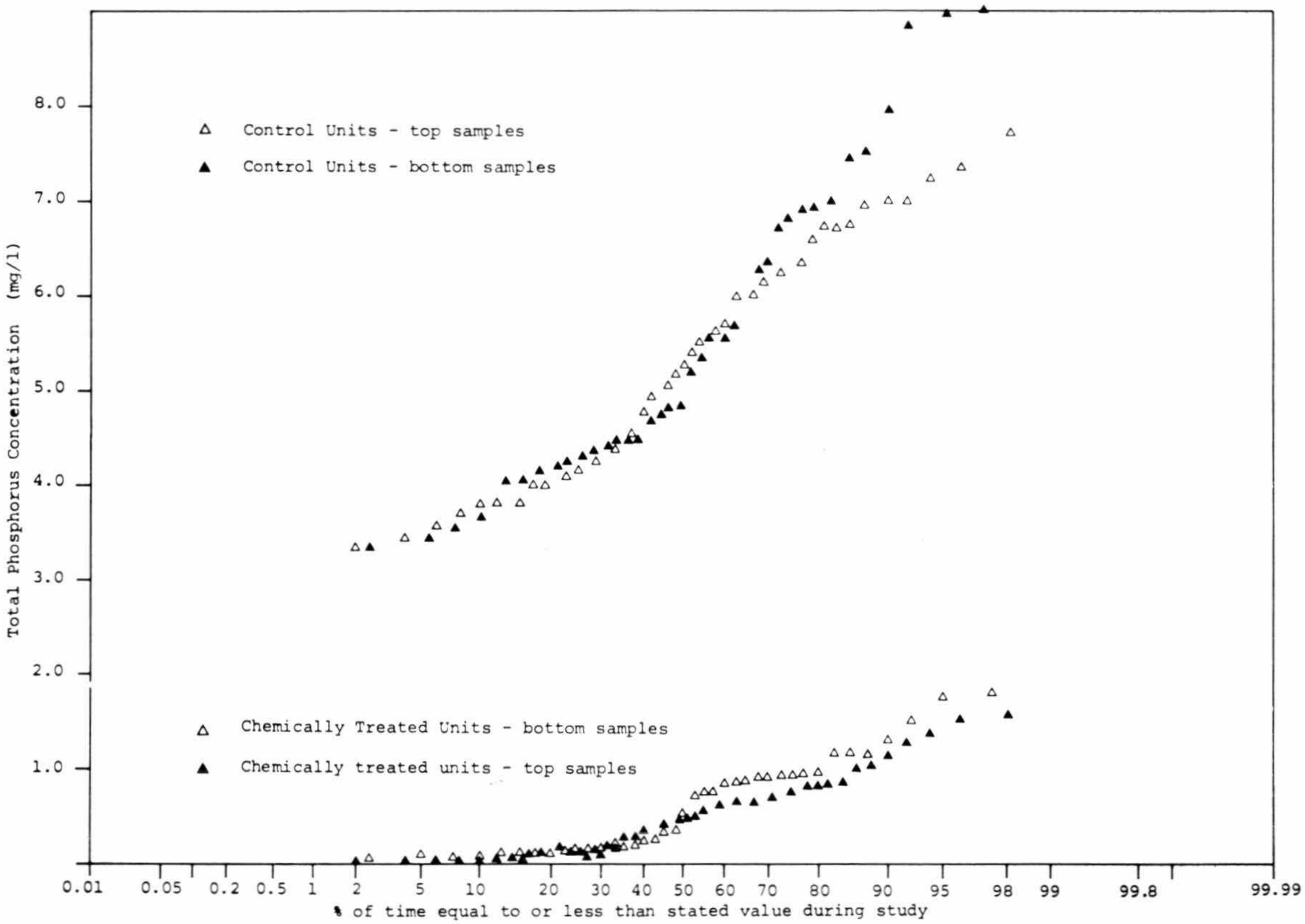


FIGURE 9 STRATIFICATION OF PHOSPHORUS IN LAGOONS AT 5°C



the probability of a given effluent phosphorus concentration but rather are used to illustrate the difference in effluent quality in the same lagoon at different temperatures or different depths of liquid.

As illustrated in Figure 7, the higher temperature resulted in higher effluent phosphorus concentrations. This is probably due to greater anaerobic activity in the sludge which will result in a higher degree of resolubilization of phosphorus. The presence of alum in the lagoon decreases the effect of temperature on phosphorus leaching. In most cases, the relative importance of temperature was small as compared to the effect of changes in alum dosages and influent phosphorus concentrations.

An attempt was made to further demonstrate that the increased phosphorus discharge was due to resolubilization from the lagoon sludges. As illustrated in Figures 8 and 9, at the respective temperatures of the study, the phosphorus concentration was monitored at the top and bottom of the units. While there is a slight trend toward higher phosphorus concentration in the bottom of the control lagoon at ambient temperatures (Figure 8), the results are inconclusive. As mentioned previously, even in the absence of artificial aeration, there is probably sufficient agitation to prevent complete stratification within the laboratory simulators.

The sludge layers were mixed with the supernatant of the units in an attempt to simulate the effect of high winds on a large surface area of a relatively shallow full-scale lagoon. The whole content of each unit was mixed thoroughly for 10 minutes and then the bulk of the heaviest sludge was allowed to settle for 20 minutes. The phosphorus concentration was measured in the filtered and unfiltered samples of the supernatant for several days to evaluate the degree of leaching from the solids. As illustrated in Figures 10 and 13, no significant increase in the soluble phosphorus concentration was detected in any of the simulators. Based

FIGURE 10 EFFECT OF MIXING SLUDGE DEPOSITS WITH LAGOON CONTENTS ON THE QUALITY OF EFFLUENT

Unit 1A (Chemically Treated)

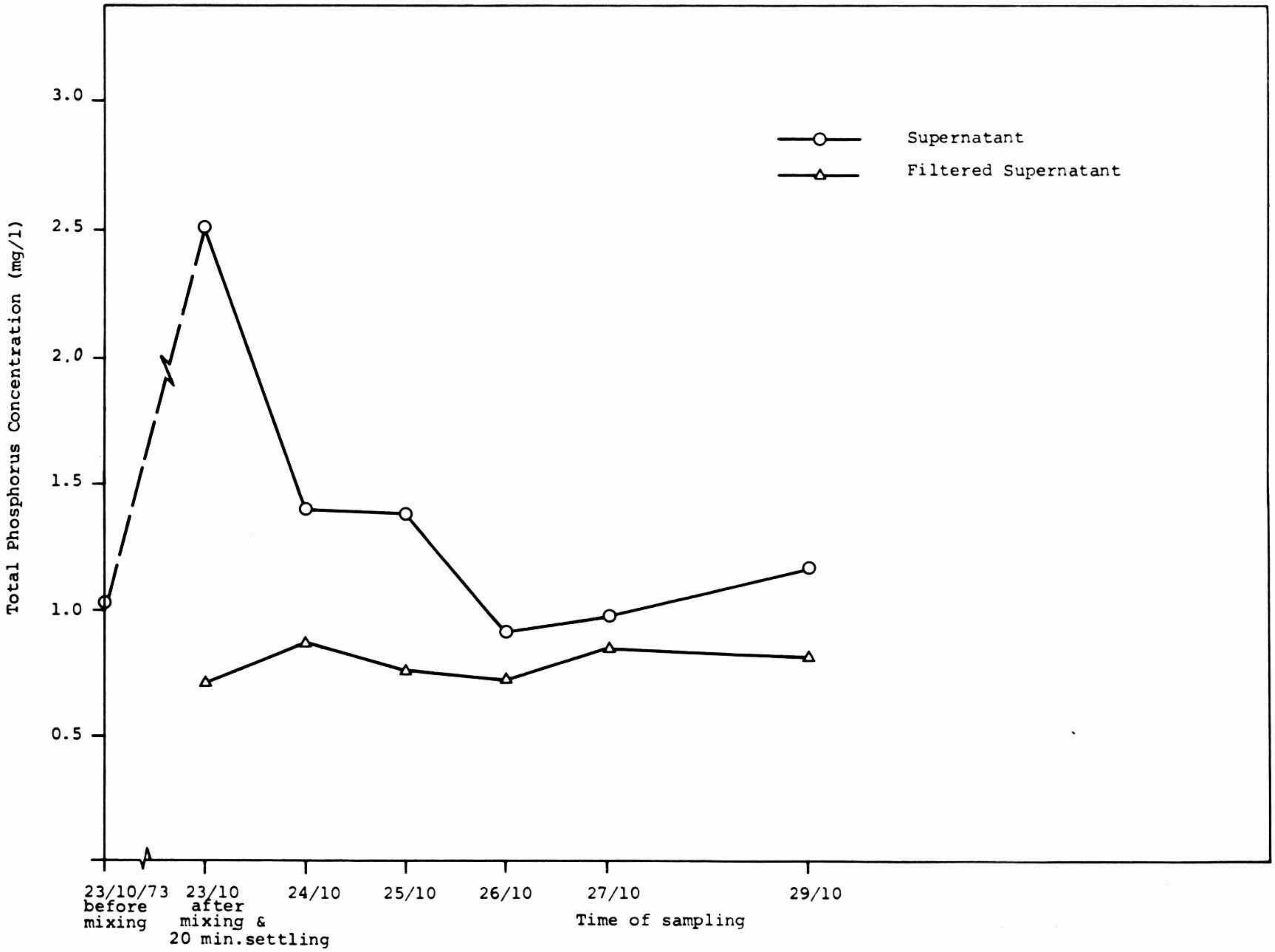


FIGURE 11 EFFECT OF MIXING SLUDGE DEPOSITS WITH LAGOON CONTENTS ON THE QUALITY OF EFFLUENT

Unit 1B (Chemically Treated)

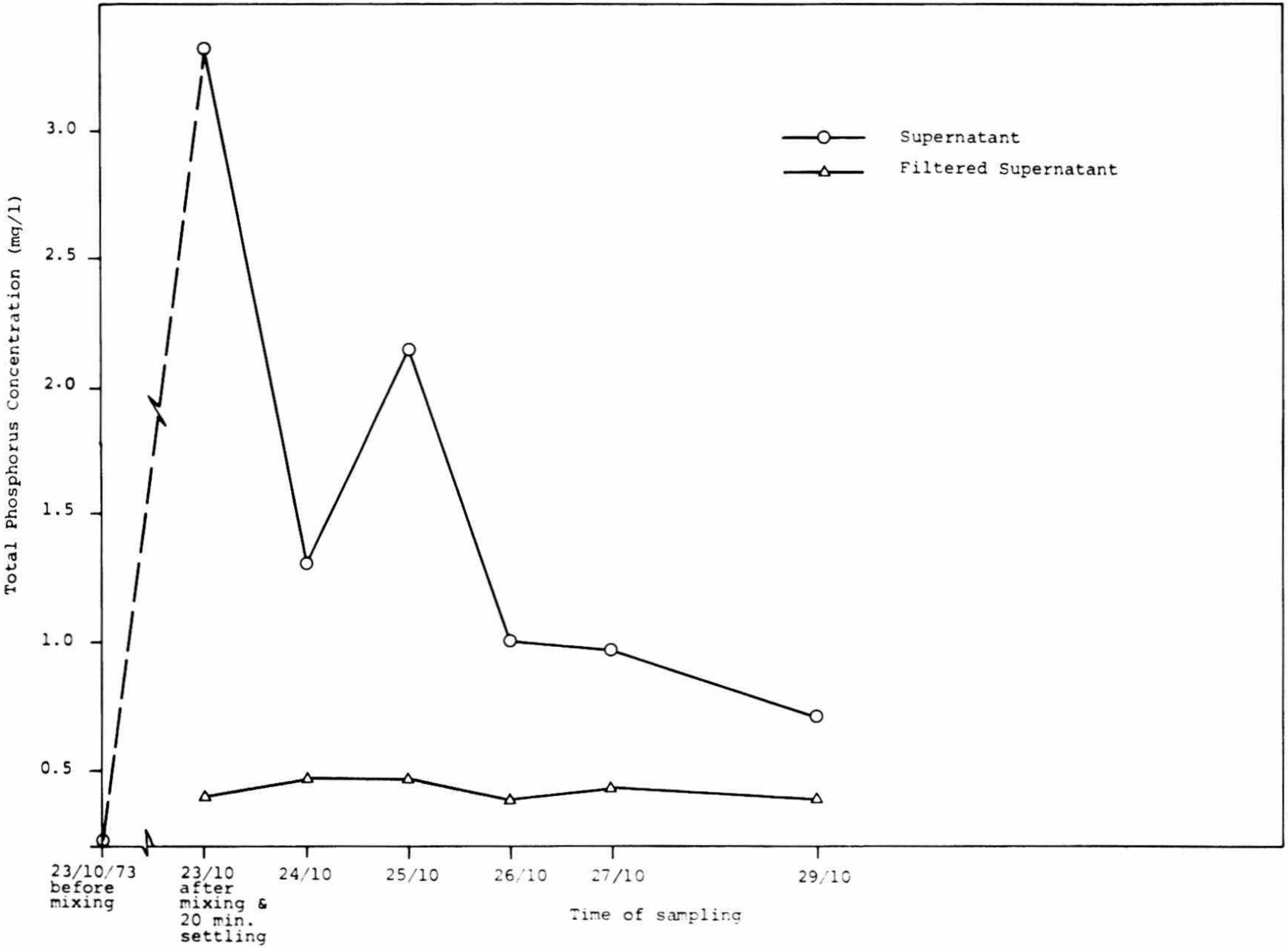


FIGURE 12 EFFECT OF MIXING SLUDGE DEPOSITS WITH LAGOON CONTENTS ON THE QUALITY OF EFFLUENT

Unit 2A (control for 41 weeks, chemically treated for last 13 weeks)

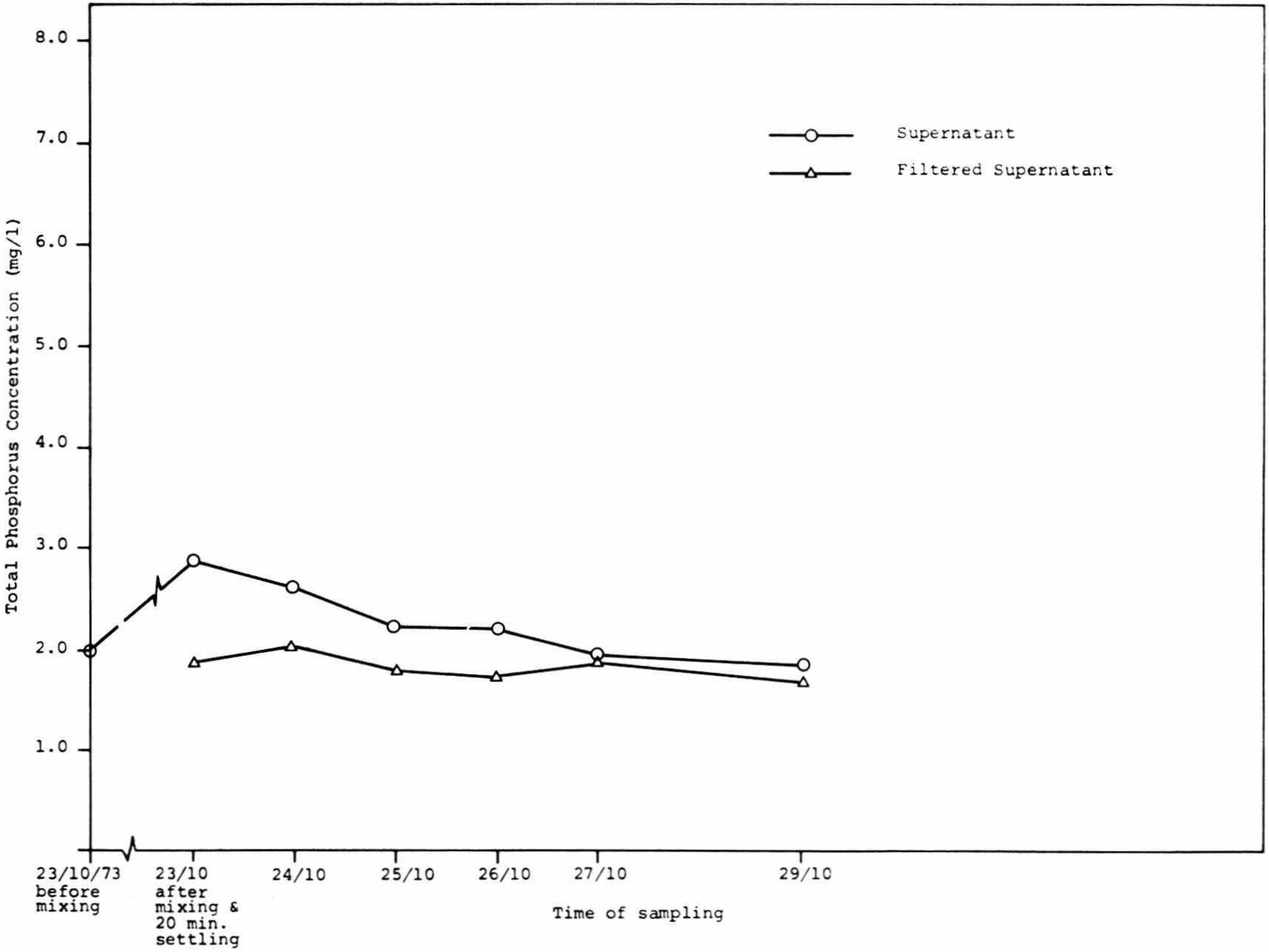
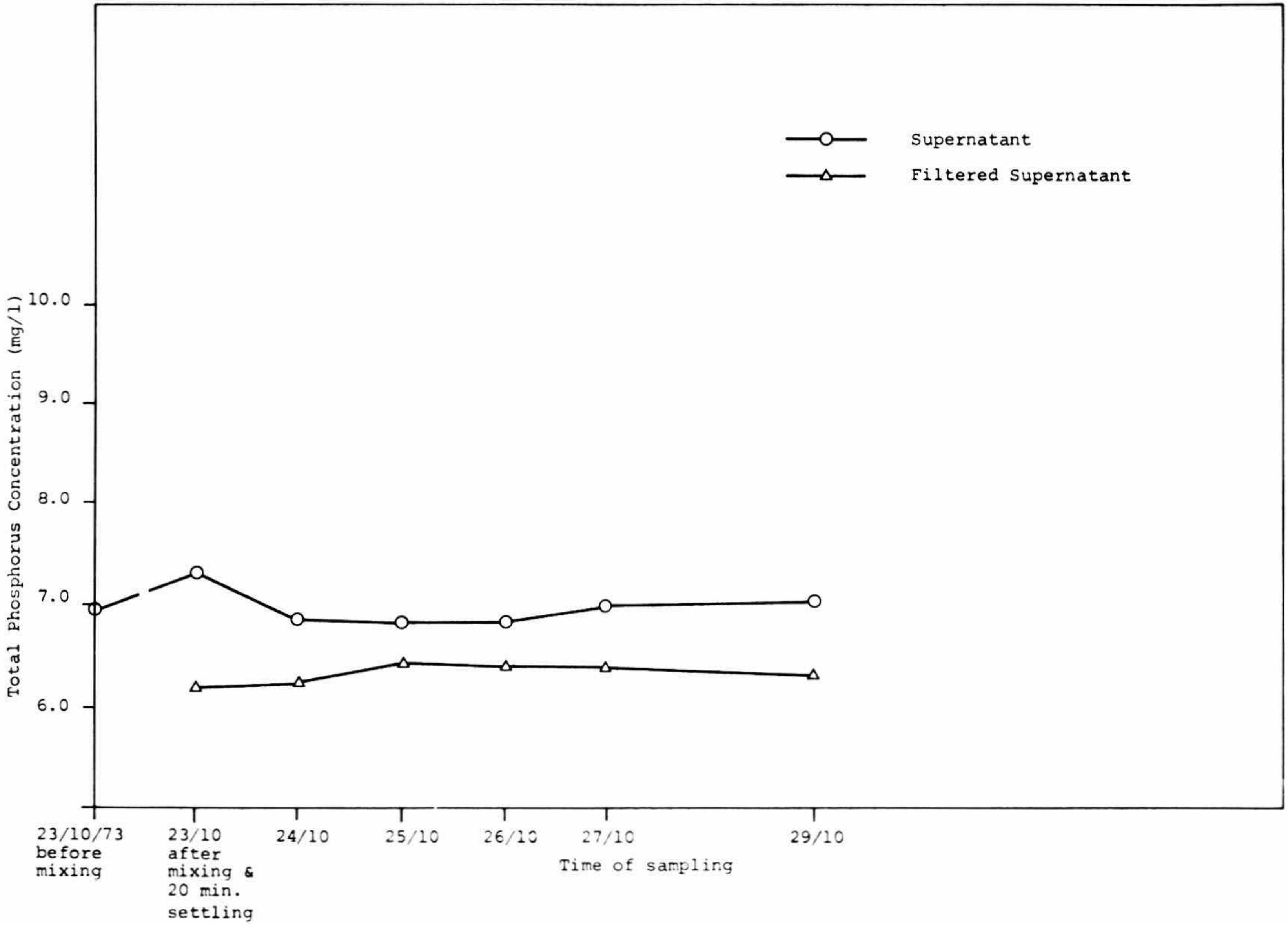


FIGURE 13 EFFECT OF MIXING SLUDGE DEPOSITS WITH LAGOON CONTENTS ON THE QUALITY OF EFFLUENT

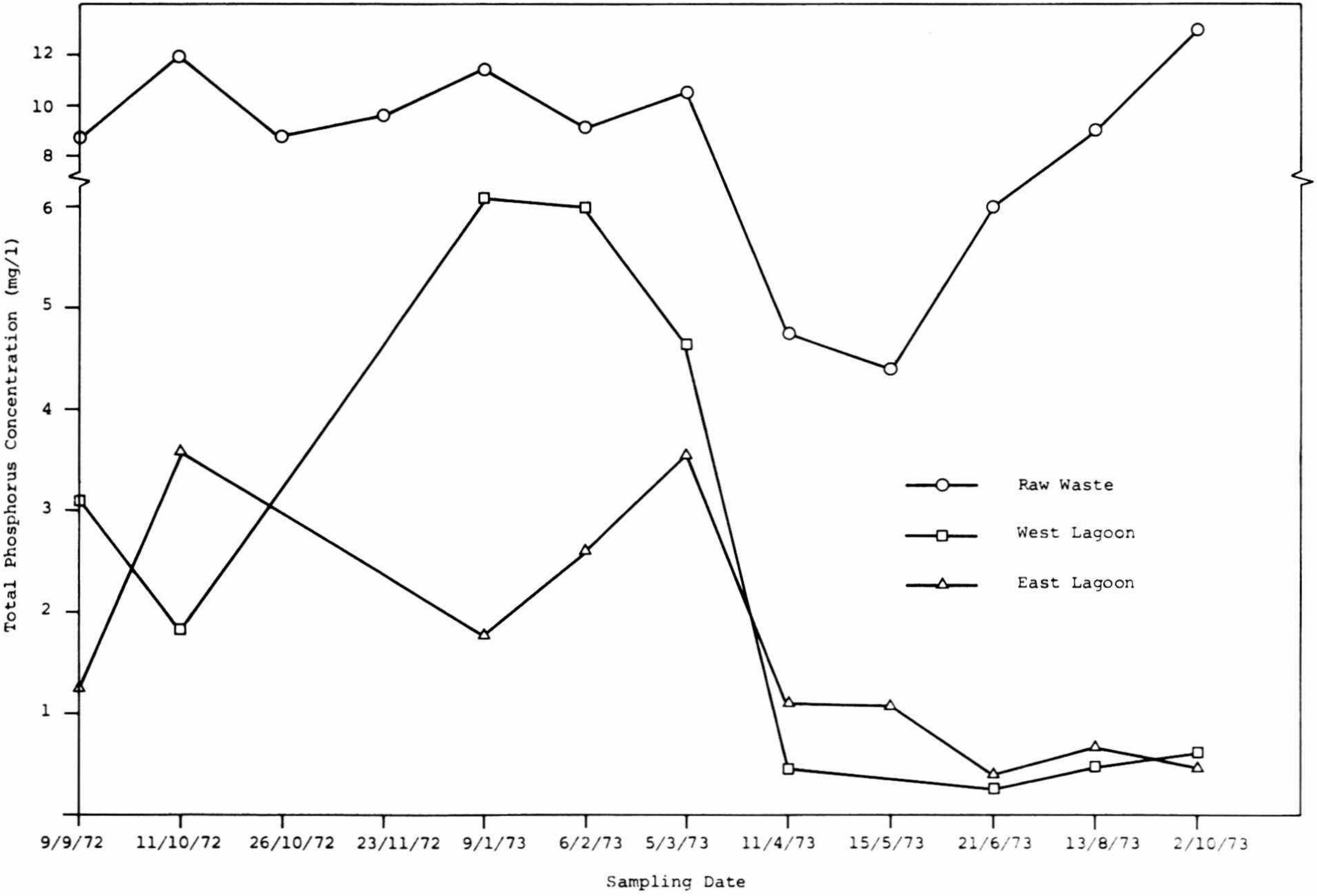
Unit 2B (control for 41 weeks, chemically treated for last 13 weeks)



on the phosphorus content in the unfiltered samples, the effluent from the alum-treated lagoons showed some decline in quality whereas the effluent from the untreated units was unaffected. The higher phosphorus content of the alum-treated sludge is probably responsible for these results.

The results of the periodical measurements taken on site at Shelbourne are summarized in Table 7 and the performance of the lagoon in terms of phosphorus removal is shown in Figure 14. Only limited data were collected from the full-scale operation, but the effluent phosphorus concentrations from the lagoons, when treated, are comparable to the results obtained from the laboratory simulators. A detailed comparison of the laboratory and full-scale lagoons was not made as data from the Shelbourne operation, as gathered by the Ontario Ministry of the Environment, were not available for the preparation of this report.

FIGURE 14 PHOSPHORUS REMOVAL IN FULL-SCALE LAGOONS AT THE VILLAGE OF SHELBURNE



6. CONCLUSIONS

Based on the results of this study, the following conclusions are felt to be valid:

1) The addition of 200 mg/l of alum to the raw sewage from the Village of Shelburne, Ontario effectively controls the discharge of phosphorus in the lagoon effluent to concentrations below 1 mg/l.

2) Higher temperatures result in increased phosphorus concentrations in the effluent from the untreated lagoon. The addition of alum at 200 mg/l minimizes this effect.

3) It is suspected that the increased effluent phosphorus concentration at higher temperature is a result of greater anaerobic activity in the settled sludge layer. However, a detailed evaluation of this hypothesis by measurement of the phosphorus gradient with depth failed to yield conclusive results.

4) The investigation of the effect of low dissolved oxygen concentration on phosphorus resolubilization did not provide conclusive results due to the limitations of the laboratory simulators. The limited data do indicate that any release of phosphorus is controlled by alum addition.

5) The alum dosage is a very important factor in the phosphorus removal process in the lagoon. All other factors investigated in this study had a relatively minor effect on the phosphorus concentration in the chemically-treated effluent.

6) Following the initiation of chemical treatment, a period of up to several months is required to attain steady state operation in a lagoon of 80 days retention time.

7) No significant change in the lagoon pH was detected during this study, and therefore the computer simulation of the process, based on such fluctuations, was abandoned. It was also concluded that the computer model did not provide realistic predictions of the phosphorus precipitation process as the phenomenon is too complex to be described by a system of chemical equilibrium relationships.

8) Mixing of the sludge deposits with the lagoon liquid did not result in any release of soluble phosphorus. However, the resuspended floc from the treated lagoons required more than 24 hours to settle and would, therefore, be discharged to a greater extent in the lagooon effluent, thereby contributing to the total phosphorus concentration in the effluent.

7. RECOMMENDATIONS

From the results of this study, the following recommendations concerning the operation of sewage lagoons can be made:

1) The addition of an appropriate dosage of alum to the lagoon influent is an acceptable method of controlling the discharge of phosphorus. As the achievement of steady state is a long-term process, it is desirable to slightly overdose the system during start-up and gradually decrease the chemical dosage to the level required for the desired degree of phosphorus removal.

2) The start-up period could be shortened significantly if the surface of the lagoon was sprayed with liquid alum at the commencement of the dosing.

3) Severe wind conditions may cause significant mixing of the lagoon contents and thereby result in an increased discharge of solids containing aluminum and phosphorus from a chemically-treated lagoon. The fate of these particulates in the receiving waters was not evaluated in this study, but they could possibly exert an impact on the ecology of the watercourse. Therefore, it would be desirable to provide a baffled, quiescent settling zone with sufficient storage capacity for the settled sludge in the area of the lagoon discharge, to prevent the unnecessary overflow of particulates.

ABBREVIATIONS

BOD	biochemical oxygen demand
^oC	degrees Centigrade
mg/l	milligrams per litre
OME	Ontario Ministry of the Environment
ppm	parts per million
WPCP	Water Pollution Control Plant
Al	aluminum
C	carbon
Ca	calcium
Cl	chlorine
F	fluorine
H	hydrogen
K	potassium
Mg	magnesium
Na	sodium
O	oxygen
P	phosphorus
S	sulphur

APPENDIX I

COMPUTER PROGRAMME

TO SIMULATE THE REACTIONS OCCURRING IN A CHEMICALLY TREATED LAGOON

```
ZLLA,T50,TP1.                                                          POLLUTECH
FTN(ROUND=+-*/,R=2)
LABEL(TP,R,D=HI,L=CHEMIST,T=60,E=02,VSN= 5226) READ/5226(NORM2)
REWIND(TP)
COPYBF(TP,LGO)
RETURN(TP)
LGO.
'       6400 END OF RECORD
      PROGRAM TST (INPUT,OUTPUT,PUNCH,TAPE5 = INPUT,TAPE6 = OUTPUT)
      COMMON AIJ(460), IROW(460), JCOL(460)                             NZ
      REAL AIJ,NAME,MWW
      COMMON /HOL8/ KA(12),KB(12),NR(60,2),KN(170),NAM(25,2),END,BLANK, NZSCO
     1   H2O,HPLUS
      COMMON /REAL8/ BBB(60,5),PH(25),T(20),BMULT(5),TOL1,TOL2,XMIN,     NZS
     1   XSTART,BARMIN,SLACKS,ALITER,RT,B(60),PIE(75),V1(75),V2(75),     NZS
     2   V3(75),V4(75),X(170),XMF(170),C(170),X1(170),X2(170),X3(170),   N
     3   XBAR(25),R(75,75),FE,FE2,ERMB,XEMB,ERMA,XEMA
      COMMON /INTGR/ M,MEND,NCOMP,N,NIT,NOT,PF,ITER,ITMAX,IERROR,LASTCP,
     1   KE,MAXM,MAXP,MAXN,MAXMD,NCYCLE,NBSTAR,KPF,
     2   NAIJ,MAXAIJ,IOPT,MTOG,MARITH,KL(26),JCOMP(170),NEMB,NEMA
      EQUIVALENCE (N,NTOT)
      INTEGER PF
      COMMON /TOGL/ IARITH,IFIND,INTITL,INSOLV,IJOHN,ILP,IMATRX,IPUSH,
     1              IROWS,ISCALE                                         NZSC0280
      COMMON/MOLER/CMW(60),Z1(60),DENSP,DENS,MWW,SMW(170),Z(170),
     1TOT,ISTOP,K,JI,JT,A1,A2,AC(170)
      CALL START
      CALL INPUT
      READ(5,100) (CMW(I), I = 1,M)
      READ(5,100) (Z1(I), I = 1,M)
      READ(5,100) DENSP,MWW,A1,A2
      CALL MWCALC(6HLAGOON,1.,MWC)
      DO 1 I =1,12
      DO 2 J = 1,N
2     AC(J) = 1.
      CALL SOLVE
      DENS = 0.
      DO 3 J = JI,JT
3     DENS = DENS + X(J)*SMW(J)
      DENS = DENS*ALITER/X(1)
      DENS = DENS*1.E-03
      CALL CORR(6HLAGOON,0.,10)
      CALL PAGE
      CALL MOLAR(6HLAGOON,1.,1)
      AL = 0.
      DO 4 J = 6,20
4     AL = AL + X1(J)
      PO = 0.
      DO 5 J = 21,28
5     PO = PO + X1(J)
      AL = 1000.*AL
      PO = PO*1000.
      ALM = CMW(12)*AL
      POM = PO*CMW(7)
      WRITE(6,200) AL,PO,ALM,POM
      TEMP = PHCALC(1)
      WRITE(6,202) TEMP
      CALL INPUT
```

```
 1     CONTINUE
       STOP
 100   FORMAT(8F10.3)
 200   FORMAT(49X,*AQUEOUS CONCENTRATIONS*,/42X,*ALUMINUM*,20X,*PHOSPHATE
      1*,/56X,*(MM/L)*,/42X,1PE12.5,16X,1PE12.5,/56X,*(MG/L)*,/42X,1PE12.
      25,16X,1PE12.5)
 202   FORMAT(///10X,*THE RESULTANT PH IN THE LAGOON   *,F6.3)
       END
'        6400 END OF RECORD
 ALUM TREATMENT OF A LAGOON OCT/23/72                  POLLUTECH
       ALUM IS BEING ADDED TO INFLUENT AT PH 7.5
        THE INITIAL PHOSPHATE LEVEL IS   3.06618E+01  MG/L
       THE ALUM DOSAGE IS 200 MG/L AS AL2(SO4)3*14H2O
MULTIPLIERS
 1.00000E+00 1. 0000E+00-0.           9.21300E-06 9.38142E-05
       CORRECTIONS ARE MADE FOR THE IONIC STRENGTH
LITER
55.34078925
LIMIT
  80
ROWS
H+            55.3407890 4.11523E-05-0.           -0.            1.00000E+00
CA+2         1.60900E-03-0.           -0.           -0.           -0.
MG+2         1.04400E-03-0.           -0.           -0.           -0.
NA+          1.29460E-03 4.84230E-04-0.            1.00000E+00-0.
-+           2.56400E-04-0.           -0.           -0.           -0.
OH-           55.3407890-0.           -0.            1.00000E+00-0.
PO4-3       -0.           3.22820E-04-0.           -0.           -0.
```

```
CO3-2        3.63100E-03-0.          -0.          -0.          -0.

004-2        5.61000E-04 1.00787E-03

F-           5.00000E-04-0.          -0.          -0.          -0.

CL-          2.05400E-03-0.          -0.          -0.           1.00000E+00

AL+3                     6.71914E-04

END

MATRIX

LAGOON

      H2O    -40.25712   1.0  H+      1.0  OH-

      H+                 1.0  H+

      CA+2               1.0  CA+2

      MG+2               1.0  MG+2

      NA+                1.0  NA+

      AL+3               1.0  AL+3

      ALOH   -23.95949   1.0  AL+3    1.0  OH-

      ALOH2  -49.26959   1.0  AL+3    2.0  OH-

      ALOH4  -93.47483   1.0  AL+3    4.0  OH-

      AL2OH2-59.1124     2.   AL+3    2.   OH-

      ALPOL7-527.8241    7.   AL+3    17.  OH-

      ALP13  -1055.6482  13.  AL+3    34.  OH-

      ALSO4  -12.62385   1.0  AL+3    1.0  SO4-2

      ALSO42-23.05135    1.0  AL+3    2.0  SO4-2

      ALF    -19.95027   1.0  AL+3    1.0  F-

      ALF2   -37.82416   1.0  AL+3    2.0  F-

      ALF3   -52.3218    1.0  AL+3    3.0  F-

      ALF4   -63.19003   1.0  AL+3    4.0  F-

      ALF5   -70.58072   1.0  AL+3    5.0  F-

      ALF6   -75.1185    1.0  AL+3    6.0  F-
```

```
P04-3               1.0  P04-3
CH2P   -60.23944    1.0  CA+2    2.0  H+      1.0  P04-3
CHP    -42.71463    1.0  CA+2    1.0  H+      1.0  P04-3
CP     -18.89472    1.0  CA+2    1.0  P04-3
MGHP   -43.10100    1.0  MG+2    1.0  H+      1.0  P04-3
H3P04  -61.94281    3.0  H+      1.0  P04-3
H2P04  -52.98238    2.0  H+      1.0  P04-3
HP04   -32.39388    1.0  H+      1.0  P04-3
K+                  1.0  K+
OH-                 1.0  OH-
C03-2               1.0  C03-2
S04-2               1.0  S04-2
F-                  1.0  F-
CL-                 1.0  CL-
CAOH   -6.63863     1.0  CA+2    1.0  OH-
CAC03  -11.38275    1.0  CA+2    1.0  C03-2
CAHC03-34.71364     1.0  CA+2    1.0  C03-2   1.0  H+
CAS04  -9.25076     1.0  CA+2    1.0  S04-2
CAF    -6.26558     1.0  CA+2    1.0  F-
MGOH   -9.96672     1.0  MG+2    1.0  OH-
MGC03  -11.84327    1.0  MG+2    1.0  C03-2
MGHC03-34.48337     1.0  MG+2    1.0  C03-2   1.0  H+
MGS04  -9.12041     1.0  MG+2    1.0  S04-2
MGF    -7.79865     1.0  MG+2    1.0  F-
NAC03  -6.93875     1.0  NA+     1.0  C03-2
NAHC03-31.23672     1.0  NA+     1.0  C03-2   1.0  H+
NAS04  -5.67520     1.0  NA+     1.0  S04-2
KS04   -6.22175     1.0  K+      1.0  S04-2
```

```
      H2CO3 -46.43819     2.0  H+      1.0  CO3-2

      HCO3  -27.79792     1.0  H+      1.0  CO3-2

      HSO4  -8.59007      1.0  H+      1.0  SO4-2

      HF    -11.31365     1.0  H+      1.0  F-

      HF2   -16.77876     1.0  H+      2.0  F-

PO4-SLUDGE

      ALPO4 -56.3814      1.0  AL+3    1.0  PO4-3

OH-SLUDGE

      ALOH3 -90.41090     1.0  AL+3    3.0  OH-

END

RETURN

1.008     40.008    24.32     22.992    39.102    17.009    94.981    60.015

96.372    19.000    35.459    26.98

1.0       2.0       2.0       1.0       1.0       -1.0      -3.0      -2.0

-2.0      -1.0      -1.0      +3.0

0.997075  18.017    0.5       0.3

      THE ALUM DOSAGE IS 150 MG/L AS AL2(SO4)3*14H2O

ALTERB2

004-2           7.55904E-04

AL+3            5.03936E-04

END

RETURN

      THE ALUM DOSAGE IS 100 MG/L AS AL2(SO4)3*14H2O

ALTERB2

AL+3            3.35957E-04

004-2           5.33936E-04

END

RETURN
```

```
      THE ALUM DOSAGE IS  50 MG/L AS AL2(SO4)3*14H2O

ALTERB2

AL+3        1.67979E-04

004-2       2.51968E-04

END

RETURN

       THE INITIAL PHOSPHATE LEVEL IS   1.83969E+01  MG/L

      THE ALUM DOSAGE IS 200 MG/L AS AL2(SO4)3*14H2O

MULTIPLIERS

 1.00000E+00 1.00000E+00-0.               9.84513E-06 1.37046E-04

ROWS

H+           55.3407890 3.92154E-03-0.         -0.         1.00000E+00

CA+2        1.60900E-03-0.        -0.         -0.         -0.

MG+2        1.04400E-03-0.        -0.         -0.         -0.

NA+         1.29460E-03 2.90535E-04-0.         1.00000E+00-0.

-+          2.56400E-04-0.        -0.         -0.         -0.

OH-          55.3407890-0.        -0.          1.00000E+00-0.

PO4-3      -0.         1.93690E-04-0.         -0.         -0.

CO3-2       3.63100E-03-0.        -0.         -0.         -0.

004-2       5.61000E-04 1.00787E-03

F-          5.00000E-04-0.        -0.         -0.         -0.

CL-         2.05400E-03-0.        -0.         -0.         1.00000E+00

AL+3                    6.71914E-04

END

RETURN

      THE ALUM DOSAGE IS 150 MG/L AS AL2(SO4)3*14H2O

ALTERB2

AL+3        5.03936E-04
```

```
SO4-2        7.55904E-04

END

RETURN

      THE ALUM DOSAGE IS 100 MG/L AS AL2(SO4)3*14H2O

ALTERB2

AL+3         3.35957E-04

004-2        5.33936E-04

END

RETURN

      THE ALUM DOSAGE IS  50 MG/L AS AL2(SO4)3*14H2O

ALTERB2

AL+3         1.67979E-04

004-2        2.51968E-04

END

RETURN

       THE INITIAL PHOSPHATE LEVEL IS   6.13235E+00  MG/L

      THE ALUM DOSAGE IS 200 MG/L AS AL2(SO4)3*14H2O

MULTIPLIERS

 1.00000E+00 1.00000E+00-0.          1.09739E-05 1.81607E-04

MULTIPLIERS

 1.00000E+00 1. 0000E+00-0.          1.09739E-05 1.81607E-04

ROWS

H+            55.3407890 3.72785E-03-0.         -0.          1.00000E+00

CA+2         1.60900E-03-0.         -0.         -0.         -0.

MG+2         1.04400E-03-0.         -0.         -0.         -0.

NA+          1.29460E-03 9.68460E-05-0.          1.00000E+00-0.

-+           2.56400E-04-0.         -0.         -0.         -0.

OH-           55.3407890-0.         -0.          1.00000E+00-0.
```

```
PO4-3       -0.          6.45640E-05-0.         -0.         -0.
CO3-2        3.63100E-03-0.         -0.         -0.         -0.
SO4-2        5.61000E-04 1.00787E-03
F-           5.00000E-04-0.         -0.         -0.         -0.
CL-          2.05400E-03-0.         -0.         -0.          1.00000E+00
AL+3                     6.71914E-04
END
      THE ALUM DOSAGE IS 150 MG/L AS AL2(SO4)3*14H2O
ALTERB2
AL+3         5.03936E-04
SO4-2        7.55904E-04
END
RETURN
      THE ALUM DOSAGE IS 100 MG/L AS AL2(SO4)3*14H2O
ALTERB2
AL+3         3.35957E-04
SO4-2        5.33936E-04
END
RETURN
      THE ALUM DOSAGE IS  50 MG/L AS AL2(SO4)3*14H2O
ALTERB2
AL+3         1.67979E-04
SO4-2        2.51968E-04
END
RETURN
CLEAR
RETURN
•          END OF FILE
```

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